PUBLISHER'S COLUMN

Cards by the sackload

We have always believed that a technical magazine can produce a very useful cross-fertilization of ideas at a number of different technical and intellectual levels. One such level is the passing from manufacturer to reader of the latest technical information. So we included in the first issue of CONTROL two sets of reader reply cards—one for readers to obtain more information about the products and services displayed in the advertisement pages, the second so that they could obtain further details about the products listed in the Buyers' Guide.

A few days before publication of the July number we installed three charming girls—Doris, Sylvia and Jenny—tentatively expecting a trickle of cards from you, the readers; confident that these three could more than handle whatever appeared in our postbag.

The first day produced 11 cards and our three girls had a nice easy day of it; the second day brought 37—rather harder going; the third day 146—an impossible task. Now nearly a month after the appearance of the first number we have dispatched over 17,000 letters to manufacturers asking them to send details on to you. We never could have imagined that so many people wanted to know so much about so many control systems and components. That CONTROL has been the catalyst in this exchange of information, we are of course pleased beyond our greatest hopes. Moreover Doris, Sylvia and Jenny tell us they still like getting cards from you.

CONTROL

AUGUST 1958 VOLUME 1 NUMBER 2

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IN THIS ISSUE

SPECIAL FEATURES

REGULAR FEATURES

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CONTROL

AUGUST 1958 VOL 1 NO 2

Not only the large works

TODAY many industrial companies find themselves grappling with more active competition than they have known since 1939. To fill their order books, sales managers must now sell, not just wait for inquiries; with shorter delivery times keener prices are becoming more decisive in winning orders. The main causes of the change from the industrial conditions of, say, 1955 are well known: although the credit squeeze is now relaxed and the American recession is halting, Britain has probably not yet felt the full swing of their effects.

For the last twelve years British industry has been continually exhorted to increase its productivity. Although some firms have achieved notable results through new management techniques, simplification and standardization, improved plant, automatic control, etc, much more could have been done, as the American and German record exemplifies. It has mainly been the larger firms that have responded to productivity drives; in the smaller works now lies the best chance of significantly raising Britain's industrial productivity. Many small and medium-sized firms have not overhauled their production methods fully because for long they have 'had it too easy'. Now manufacturing costs, for some firms, are bearing not only on the nation's economic future but on their own.

Various ways are open to the manufacturer who is actively trying to cut costs. One is to modernize plant, and the Chancellor recognized the value of this when two months ago he raised the initial allowances for capital investment in plant and machinery. Frequently a rewarding method of modernizing plant (including machinery) is to fit more instruments to it. The plant may be for glass-making, dyeing, baking or brewing; it may be in a laundry, a rubber factory, a paper mill or a plating works; it may be an evaporator, a heat treatment furnace, a machine tool or an assembly line. But without question the plant engineer could raise the technical and economic efficiency of his plant in many works by the use of appropriate instruments —flowmeters, pressure and temperature recorders, gas analysers, automatic timers and weighers, to name but a few. Increasingly such instruments will work with controllers as production becomes more automatic. This need for instruments is especially relevant to smaller firms, many of which are apathetic about using more instruments than are essential for safety and for manual operation.

Appropriate instruments and their economic possibilities vary of course from plant to plant. But one type of instrumentation is widely applicable: although used in numerous works, it should be installed in more. This is automatic boiler control; in small works too many boilers, particularly solid-fuel ones, are still without it. It is important for the best use of the country's fuel resources, apart from the economic saving it provides. Furthermore, the Clean Air Act makes the fitting of boiler instruments even more desirable, but since it came fully into force on 1st June the rate of installing them has increased only slightly. No doubt the first prosecution for making dark smoke will raise the tempo.

How can a manufacturer or his plant engineer find out about instruments likely to benefit him? Probably his best method is to approach instrument firms that specialize in instrumenting his particular type of plant. Most firms provide a consulting service for potential customers. A manufacturer can of course obtain independent advice from a consulting engineer, though he may have difficulty in finding one with appropriate experience. The National Industrial Fuel Efficiency Service gives advice about boiler control for only a nominal charge. One of the instrument manufacturers' associations or the association covering his own industry will often be able to put him on the right road. Moreover, a potential user of instrumentation can always write to CONTROL and we will do our very best to help.

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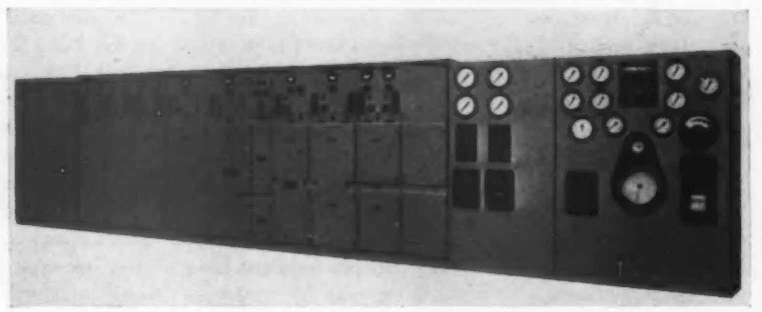

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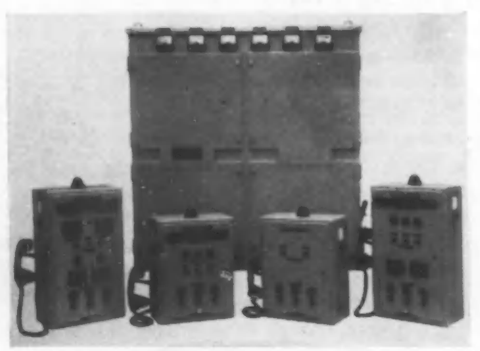

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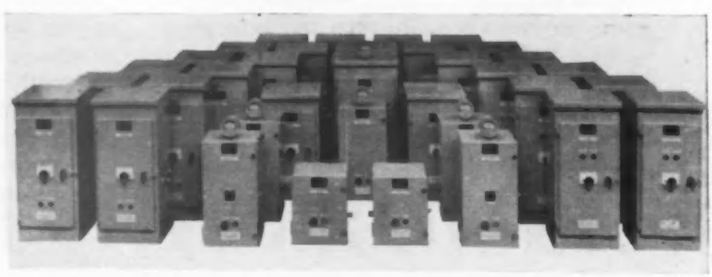

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SIR! LETTERS TO CONTROL

The Editor welcomes correspondence for publication

Out of many letters received about the first issue of CONTROL *we have selected the following for publication. We thank correspondents for their congratulations and rather wish we had been offered more criticism!*

SIR: CONTROL certainly is impressive and I believe will have a very good future, since evidently the editors agree with the very cogent views of Mr Adkins on p A53: one is sick of unending pseudo-technical journalism.
Cleaver-Hume Press Ltd P. EDMONDS

Credit and criticism

SIR: I look forward, with you, to many years of continued achievement in this ever widening field of control engineering. To make these years even more fruitful let us all encourage those who have stories to tell. Let us hope that more engineers will put pen to paper and share the excitement of invention and developments with others. It is essential that British engineers should be given the publicity they deserve. Britain's share of world publicity often seems to be subjected to political ignorance and misunderstanding (e.g. ZETA 1958). Therefore, let credit be given to all who add to our knowledge of this intricate and complicated subject of control. With credit must go criticism. Let that also be given when necessary.
Kelvin and Hughes Ltd J. BRIGGS

● CONTROL *will surely do these things. Engineers who are 'too busy to write' please note*—EDITOR.

Delicacies only

SIR: To me the first issue of CONTROL comes at an appropriate time since I am, after twenty years, leaving the practical side of instrument work to begin teaching the craft. In that period I have seen a considerable change in the relevant technical literature on the subject. In the early days the *Journal of Scientific Instruments* issued by the Institute of Physics was practically the sole source of information on current practice and new instruments. Today, as others of your correspondents have said, there is a spate of instrument journals. At one time we would have welcomed such a venture as CONTROL with unqualified enthusiasm. Now the appetite is satiated and one only becomes cognisant of the delicacies. Hence it follows that I think a lot of your magazine or I would not be at the typewriter now.

Two points of criticism. First, why intersperse advertising with the text? It may please the space salesman and the advertiser, but how it annoys the reader. Second, I think the Buyers' Guide is of very limited use; its inclusion in each issue will make a bulkier and more expensive journal which will more rapidly overload the subscriber's shelf.

I like the transfer function page and the *Control Survey* in particular, whilst the technical quality of your articles needs no comment that it is competent for me to make.
Stoke-on-Trent A. M. GAYES

● *Thank you, Mr Gayes. Our Publisher comments on your points about advertising and the* Buyers' Guide *as follows: 'No advertisements are interspersed with the main editorial feature pages of* CONTROL. *A few appear alongside or facing editorial matter at the beginning and end of the magazine, primarily to enliven pages that do not carry*

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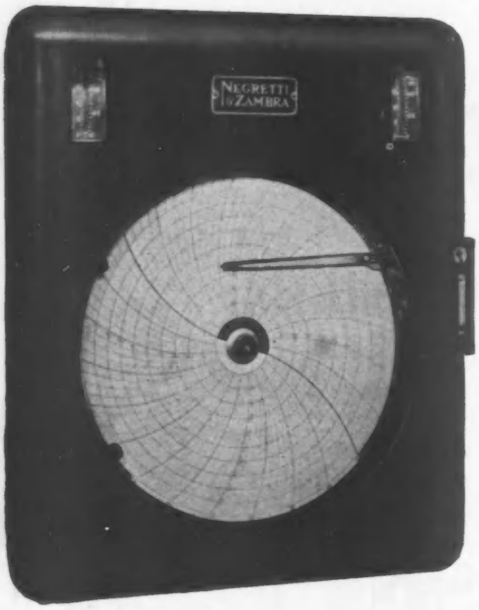

Set-up procedure is extremely simple — a particular advantage where it is necessary to close down the plant periodically, as resumption of automatic control can be rapidly effected. Further advantages are:

- NO INTERACTION BETWEEN TERMS, ***enabling the controller to embrace wider plant characteristics than are possible with interacting controllers.***
- IDEAL BASIC CONTROL RESPONSE ***generated under all conditions.***
- TRUE VALUES ***of Proportional Band and Integral and Derivative Action Times are calibrated on the various units.***
- OPTIMUM PLANT CONTROL ***can be methodically and rapidly effected.***
- TRULY CALIBRATED PLUG-IN UNITS ***allow easy replacement without re-setting and facilitate servicing.***
- EASILY CONVERTIBLE—***thus a two-term controller may be used with either Derivative or Integral Unit, and three-term controller with both units.***
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SIR!

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Autocontrol on the railways

SIR: I wonder if you have considered including articles on railway signalling among the topics which you intend to cover. There are considerable developments coming forward in this field: in this country the centralizing of signalling schemes and installation of warning control—and probably automation of level crossing operation if Parliament sanctions lifting barriers. In America automation of sorting yards has gone much farther: punched tape to set the points for sorting a whole train load of wagons; determination of weight, speed and rollability of each wagon by suitable measuring devices; combination of this information with the number of wagons already in track in an analogue computer, which determines suitable release speed from the retarder for the wagon in question; the retarder braking the wagon down to the correct release speed as measured by radar or ultrasonic beam—and then letting the wagon run. Whether late or early these techniques will probably come to the UK.

Hampton-on-Thames R. J. POST

● *Certainly we hope to cover automatic signalling, automatic train control and the allied topics Mr Post mentions, particularly as feedback and computer techniques are increasingly applied to them. Perhaps some of the ground is on the fringe of control engineering, as understood at present, but it seems clear that engineers with an instrumentation and control outlook will have increasingly varied applications to deal with in the future. There is a report about London Transport signalling in* Control in Action *this month*—EDITOR.

Precision gears

SIR: May I congratulate you on the excellent quality of production of the first issue of CONTROL.

In the Buyers' Guide I have failed to notice any reference to suppliers of gear cutting and shaving machines and tools of the type essential to the production of the precision gears used in control systems, tabulators, and many types of instrumentation.

Whilst many manufacturers of the latter types of product purchase gears from an outside source, a great many more prefer to produce their own precision gearing because of the extreme accuracy required.

W. E. Sykes Ltd R. SMITH

● *Thank you very much. We agree that precision gears are most important;* CONTROL *Buyers' Guide should have included them, and will in its next issue. The Guide does not set out to list manufacturers of machinery for making components, and although we appreciate the force of your remarks, we do not consider that precision gear cutting and shaving machines should really find a place in it*—EDITOR.

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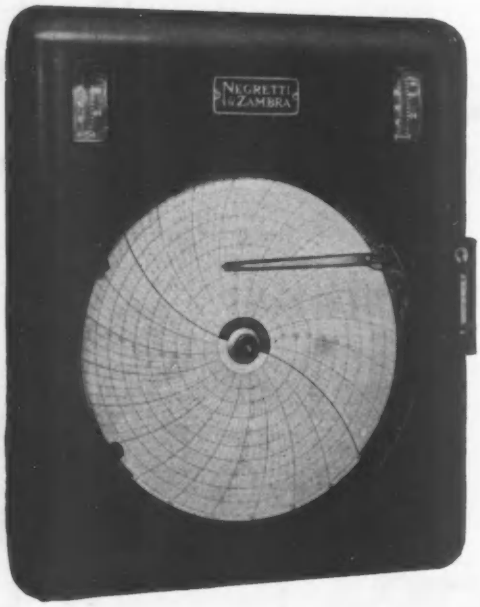

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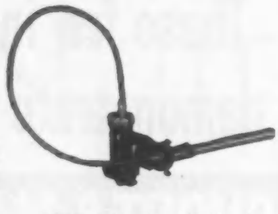
Not  only 

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INDUSTRY'S VIEWPOINT

A monthly article by a prominent man in the control industry on a subject chosen by himself

THE ELECTRICAL MEDIUM

by **W. T. MARCHMENT**
Instrumentation and Control Manager, Evershed & Vignoles Ltd

The infinite variety of the electrical medium is one of the greatest factors in the progress of instrumentation and control engineering.

Apart from the incredible number of effects which can be produced by the medium, there are a variety of electrical effects resulting from changes in physical or chemical condition which form the basis of detection and, eventually, control. It is indeed remarkable that only recently have many of the laws, observations and effects been put into practical use on a large scale.

It is doubtful whether Dr Ohm, when introducing his law and expressing the ratio between voltage and current, would have thought that today we should be using similar electrical ratios for air/fuel or air/steam ratios in combustion control, or that the conductivity of liquids would be indicated by an ohmmeter.

Would Bernoulli have imagined that the principle of the dynamometer wattmeter would have provided a means of correcting his square-root flow law? He would have been more amazed at the electromagnetic flowmeter which uses the Faraday effect, and in which an electrical conductor (the flowing liquid) moves in a magnetic field, the flow velocity being indicated by an e.m.f. appearing across the section of the liquid in the field. He would have undoubtedly been fascinated by one of the most important advantages of electromagnetic flowmeters—the measurement of true mean velocity being independent of velocity profile.

Evershed observed that insulation resistance varied with moisture content in the material, and this effect is utilized today in one form of humidity detector in which a ceramic material varies in resistance in accordance with the amount of vapour adsorbed. The Seebeck effect, probably the best known to engineers, was discovered by Seebeck in 1821 when he produced thermo-electric currents by heating at a junction between two dissimilar metals. Thermocouples are widely used today for temperature measurement.

Dielectric action, discovered by Faraday, plays an important part in modern control engineering, and capacitances are associated with most electronic circuits. A change in capacitance is sometimes used to initiate control in servomechanisms, and also in some proximity meters for the detection of levels of liquids or solids in containers. More recently, the charging and discharging of a capacitance in electronic control has been used for integral action and a resistance-capacitance network for rate action or derivative action.

The electrical resistance of materials alone provides a solution to many control problems. Loads may be measured by change of resistance in a strain gauge due to an increase or decrease in tension, or the change may be due to a rise or fall of temperature in resistance thermometry. It is interesting to note that the temperature-sensitive compounds which are used in thermistors have a negative temperature coefficient. This useful property can provide temperature compensation by opposing the positive coefficient of the normal pure metal resistances.

Fleming, by his introduction of the thermionic valve, was largely responsible for making possible the use of many electrical effects in instrumentation and control, for the valve enabled the detection and amplification of weak signals. The more recent electronic devices associated with nucleonics have further emphasized the significance of his contribution. He indeed would have been the first to realize the importance of the semiconductors or transistors of today.

With a medium of such variety it is only natural that managements are becoming increasingly aware of its potentiality. Analogue and digital signals are being converted to print out for record purposes for accounts and statistical departments, and complex calculations are being rapidly made on computers, with a considerable resultant saving in man-hours.

Managements are also impressed by the possibility of automatic quality control in the process industries, and already progress has been made towards the automatic factory.

It would seem that the rapid advance in nuclear power with its unlimited supply of electrical energy, and its undoubted use in the industrial processes of the future, will provide yet further opportunities for the electrical medium in instrumentation and control. Its scope can indeed be adequately indicated only by the symbol ∞.

Steel Manufacture

the scope for control systems

by **C. B. CHERRY**

Head of Instrument Department, Stewarts and Lloyds Ltd

The iron and steel industry is basic to our economy. To increase productivity more and more plants are being fitted with automatic control. Here is how it is being applied to:

1. Blast furnaces
2. Open hearth furnaces
3. Soaking pits

RAPID STRIDES have been made in the last eight to ten years in the use of many forms of automatic control in the iron and steel industry. This has mainly been for temperature, flow or pressure control and almost always involves a closed-loop system, where any deviation from desired value is corrected by a recorder-controller.

Most modern iron and steel works can be divided into three units, each of which plays its own part in the production of the final end product:

a. Blast furnaces, where the iron ore is used in vast quantities for the making of pig iron, ultimately to be distributed to foundries for castings, or to be used in the right proportions in the making of steel ingots, when it is added in the molten state to open hearth furnaces.

b. Open hearth furnaces, where steel scrap is melted and pig iron added to finally complete a cast or 'heat' of molten steel. Throughout its nine to twelve hours (dependent upon the size of the furnace), it has been sampled and analysed by the chemist and checked for temperature by the use of quick-reading immersion pyrometers, so that temperatures, specification and quantity are all correct before teeming into moulds for ingot manufacture. The furnace roof temperature is measured by a radiation pyrometer (Fig. 1).

c. Soaking pits, where the ingots are reheated to enable the rolling mills to reduce the ingots to a bar, billet, slab or sheet for the manufacture of girders, tubes, etc.

The above stages have their own demands on the instrument industry for controllers of various types to enable each of these specialized processes to proceed on modern lines. The following is a review of the processes from the control angle.

1 BLAST FURNACES

The actual function of a blast furnace need not be described here as we are primarily concerned with the operation and control of such a furnace and its by-products. Fig. 2 shows a section through a blast furnace together with a schematic of the instruments an operator needs. The actual temperature control of conditions inside a blast furnace is governed by many factors, the rate at which the raw material is fed in at the top, the ratio of coke to ore, the volume of hot air blast blown in through the tuyères and the temperature of the hot blast. Now the sequence and the rate at which the raw materials are fed to a modern furnace are usually handled in one of two ways: either by the operator who, with push-button control, can select at will coke or iron-ore to be charged; or by setting a sequence timer which carries out a similar function on a preset programme, this programme being arranged to suit the immediate conditions of types of ore available and furnace operating conditions.

The volume of hot blast is under the control of an operator. The temperature, however, is automatically controlled. It is a simple closed-loop system where the measurement of temperature by an exposed-tip thermocouple is fed to a temperature recorder-controller of the pneumatic type, which positions a power cylinder connected to a butterfly valve in a cold blast main, allowing the correct addition of cold air to maintain the desired value. Automatic control of this temperature is very critical as the performance of the furnace depends on this to avoid 'hanging' of the load—a condition where the charge in the furnace sticks and fails to move

progressively down towards the hearth. A system such as this is usually quite capable of control of temperature within $\pm$ 5 deg C, when handling a volume of blast in the region of 60 000 to 70 000 ft³ per minute.

The valuable by-product of blast furnace gas needs to be cleaned before passing either to the gasholder for storage or to other users in the works for heating. A washing process and electrostatic precipitators are usually employed, again with extensive flow and pressure control. The gasholder itself has sensitive level and pressure control units associated with it, together with height transmitting and indicating systems for the benefit of those responsible for gas distribution. All these systems must be installed and designed for long periods of continual rugged operation, for unlike reheating and steel melting furnaces, a blast furnace will continue to operate for some years before it is taken off for repairs or overhauls, and it is not shut down for holiday periods.

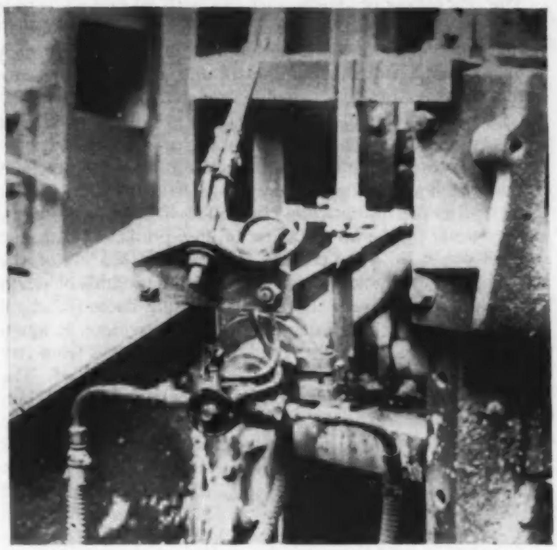


Fig. 1 A roof-temperature radiation pyrometer must be rugged to survive

2 OPEN HEARTH FURNACES

Now let us pass to the furnaces responsible for the manufacture of steel, which are usually of the open hearth type, where the 'hearth' or 'bath' is capable of holding and refining 100 tons or more of molten steel. It is now more the rule than the exception to find an open hearth furnace which has some form of automatic control built into it. This is a quite logical outcome when one considers the small working margin between the temperature required for the process and the maximum safe temperature of the refractory materials used in the open hearth furnace construction, the most vulnerable part of the structure being the arched roof, which can be damaged so easily, necessitating the furnace being out of production for some days for repairs to be made. Furnace roof temperature measurement has been in existence for some years both in this country and abroad and invariably consists of some form of radiation pyrometer focused on the part of the roof most likely to be at the highest temperature. This then is the first step in applying automatic control to the fuel input to attain and maintain the roof at its preset value.

Once an efficient roof temperature measuring unit has been installed, linking of this into a closed-loop control system in one form or another is comparatively simple. The choice of instruments must be made carefully, the working conditions are severe as dirt, dust and high ambient temperatures all have to be contended with, and robust panels and structures are essential. With the increased use of fuel oil the job to some extent is simplified as one has to deal only with pipes of diameter up to 4 in., in which diaphragm control valves are fitted.

Producer gas-fired furnaces

Producer gas-fired furnaces, which can be controlled very successfully, have gas mains some 3 ft or 4 ft in diameter. They are almost always brick lined, where the fitting and operating of a valve or throttling device becomes a heavy engineering job. Fig. 3 shows in diagrammatic form a producer gas-fired open hearth furnace, automatically controlled, where the gas valve problem has been overcome by the use of a system which controls the 'rate of make' of gas, dependent upon furnace demands. It will be seen from Fig. 3 that the higher reading of two radiation pyrometers both focused

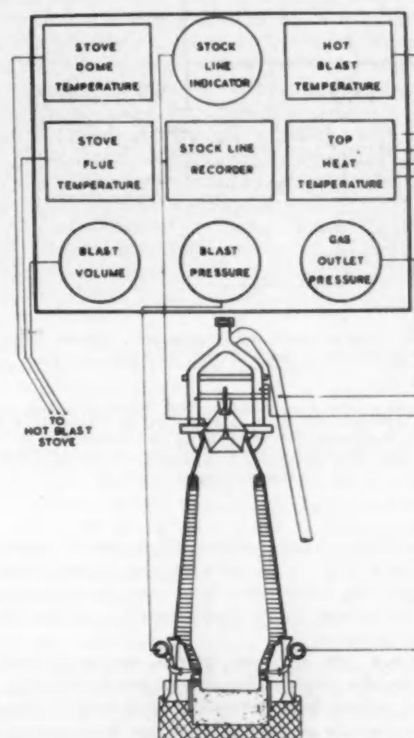


Fig. 2 A blast furnace—and what an operator needs to know about it

on the furnace roof is selected to be the 'measured value' by instrument 3. This reading is switched to pneumatic controller TCR 1, which positions the setting point on An 1 and is the 'load signal'. This in turn controls the rate of coal feed by positioning a power cylinder, and controls the volume of air blast by regulating the steam supply to a steam-driven air fan 1. The steam used for this purpose is mixed with the

air and forms the saturated blast, the temperature being finally trimmed by TC 2.

As the coal feed and blast volume are operated on a proportional basis, it is necessary, under certain conditions dependent on the type of fuel etc., to increase or decrease the coal supply slightly to maintain a preset gas offtake temperature—this is taken care of by TC 1. This complete unit is duplicated on an identical producer, the result being

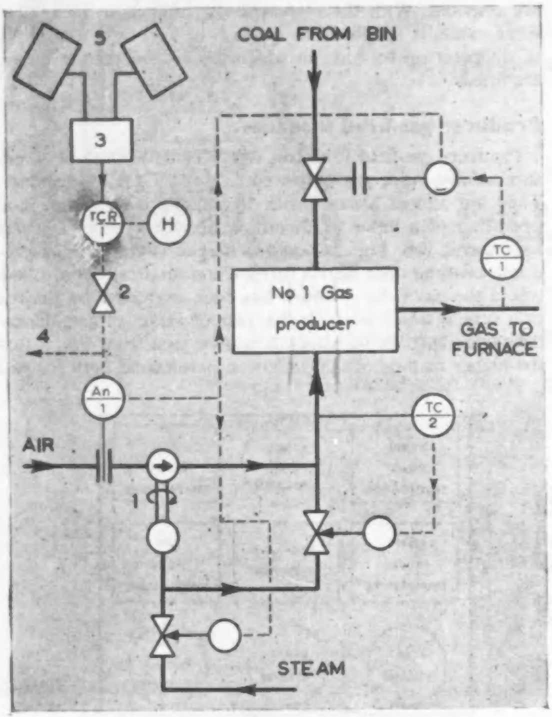


Fig. 3 A producer gas-fired furnace with simple loops to regulate the streams of coal, steam, air and gas

1 Steam-driven air fan; 2 Solenoid lock valve; 3 Selector for the higher of the two pyrometer readings; 4 To an identical No 2 producer; 5 Roof temperature pyrometers; **An 1** Ring-balance load controller with limit stop; **TC 1** Gas temperature controller; **TC 2** Blast saturation temperature controller; **TCR 1** Roof temperature controller-recorder with manual-control station on furnace panel

a correct volume of gas, temperature corrected, made and controlled according to the steel making furnace demand. The solenoid lock valves introduced into the circuit are to hold the instruments at a stable reading whilst furnace reversal is in progress.

Where mixed fuels are used various means of including fixed or adjustable ratio setting devices can be included, and air-operated systems lend themselves admirably for this purpose. A considerable amount of work has been done to link fuel input to combustion air flow, thus enabling definite ratios to be maintained.

It will be appreciated that the measurement of accurate air flow for combustion purposes presents something of a problem on most types of open hearth furnace. Whilst it is comparatively simple actually to measure the forced or induced flow of air at the intake, this may or may not be the true quantity which is being used for combustion. Here furnace pressure control can be introduced, not necessarily as part of a closed-loop temperature control system, but as an essential refinement in an attempt to obtain standard conditions so that unmeasured air infiltration is kept to a minimum. Pressure control for that one purpose of preventing, as far as possible, unmeasured and also unheated air (remembering again that an open hearth furnace is of a regenerative type) from entering the furnace body, does allow a more accurate and consistent fuel–air ratio to be maintained. It appears that the next step towards fuel–air ratio controlling will be where the installation of an oxygen recorder controller, continually sampling waste gas for oxygen content, is used for accurate air ratio purposes. Although the sampling conditions are somewhat severe, with high temperatures, dusty and corrosive atmospheres to contend with, which call for extensive cooling and filtering of the sample, this does seem to be the way to efficient fuel usage.

So much for some of the problems of automatic control of gas-fired open hearth furnaces.

Oil-fired furnaces

The controlling of similar furnaces with oil firing is a little easier from a general engineering aspect. Extensive use of diaphragm valves is made and a 100 ton oil-fired furnace with automatic temperature control and automatic or semi-automatic reversing gear usually has six or more such valves. An example of an oil-fired furnace is given in Fig. 4. The fuel is either heavy fuel oil or one of the coal tar fuels. In any case it has to be stored in heated tanks and all the pipelines heated and lagged. The temperature is critical within certain limits and is thermostatically controlled. The oil is atomized at the burner by the introduction of high-pressure steam, the ratio of which, with the oil, has an important bearing on the type of flame available. Ratios of 7 or 8 to 1 (pounds of steam to gallons of oil) give a short, sharp cutting flame for rapid melting of scrap. The essential first measurement is again roof temperature, the higher reading being selected from two or more radiation pyrometers situated on the roof. The actual position for the pyrometers is much more critical than with a gas-fired furnace owing to the very rapid response when a fuel oil is used. This measurement is converted via a potentiometric recorder-controller (after comparison with the desired valued point) into a 3 to 15 lb/in^2 air signal which sets the control setting pointers on oil flow, steam flow and air flow meter controllers. Each of these meter controllers in their turn pneumatically control a diaphragm valve, or butterfly valve in the case of the air flow, to conform with the plant demand. The ratios of air to fuel and steam to fuel are catered for by manually adjusted units available to the furnace operator to adjust as required. The whole of this apparatus is usually divided into three units: that fitted to the furnace structure; that fitted in the pipelines and air ducts; and that fitted to an instrument panel. The general practice is to group all diaphragm valves, orifice plates, filters and pressure stabilizers on a valve platform with as much room as possible for maintenance purposes. The instrument panel, invariably difficult to site on a melting shop landing, has usually to be tucked in between charging machine rails and railway tracks. It is quite often mounted on some shock absorbing units and has a fairly robust housing around it, which can be pressurized to exclude the ever present dust.

To assist in the fine and accurate control of a furnace of this type it is essential that fuel and steam pressures remain as stable as possible, and with that in view it is now an added refinement to include oil and steam pressure-stabilizing valves to maintain as closely as possible fixed operating conditions. All this has finally resulted in obtaining extremely good automatic temperature control on a type of furnace which has always been considered as being the most difficult of metallurgical furnaces to control, with the result that the furnace operator can devote the whole of his time to the manufacture of the product without damage to the furnace.

Before leaving the open hearth furnace, it perhaps should

be mentioned (although having no part in automatic control) that it is now a regular routine practice to obtain temperatures of the liquid steel by immersion thermocouple to complete the important information made available to the smelter. The temperatures are obtained by a large 'wheeled thermocouple' which consists of a Pt–Pt/Rh thermocouple fitted inside a main tube, insulated throughout its length with glass-fibre sleeving and refractory beads within a few inches of the hot junction. The wire here is left bare to keep the speed of response as high as possible and a fused silica closed end tube is fitted. It is immersed in the molten metal for about 20 to 25 seconds, in which time a high-speed recorder will have obtained a steady reading.

Bessemer convertors

It would not be right in a survey of this description to ignore any reference to the Bessemer method of steel making, a method in use probably more on the Continent than in Britain. It still is, however, a unique process which requires no additional heat to convert liquid iron from a blast furnace

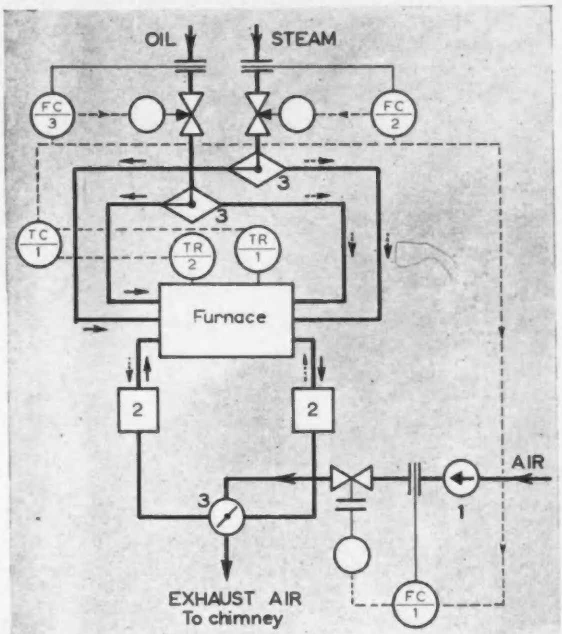


Fig. 4 An oil-fired furnace has simpler engineering but faster response than gas-fired furnaces

1 Air fan; 2 Checkers; 3 Reversing valves; **TR 1,2** Roof temperature radiation pyrometers; **TC 1** Roof temperature controller; **FC 1** Air flow controller with set point positioned by roof temperature controller and ratio linkage; **FC 2** Steam flow controller with set point positioned by roof temperature controller and steam oil ratio linkage; **FC 3** Oil flow controller with set point positioned by roof temperature controller.

The direction of the burning is changed by reversing the three valves (3).

The operation of the furnace is in the direction given by the line arrows for about 20 min and then for the same time in the direction given by the broken arrows

to steel. Some 20–30 tons of metal at a time are handled and the normal refining time is about 14–18 minutes. A convertor consists of a container into which molten iron is poured and a high-pressure air blast is introduced at the base to start the oxidization of phosphorous and carbon, etc. The technique is still very much dependent on the skill of the experienced operator and leaves something of a gap in the instrumentation of a comprehensive steel plant. Temperature measurement of the bath is a matter for experiment, and various types of photocell and radiation units are being employed to put this important aspect of Bessemer control on the same basis as in an open hearth furnace. Anyone who has seen a Bessemer convertor in operation will appreciate the challenge it makes to the instrument manufacturer and user to bring its instrumentation up to the standard of other parts of an iron and steel works.

3 SOAKING PITS

This brings us now to the final item in our survey of instrument installations, namely the soaking pit. This is a large brick-lined pit with detachable lid or roof built either above or below ground level, capable of holding 50 tons or so of ingots which may each be from 2½ to 5 tons in weight. Suitable lifting apparatus is available for loading and unloading purposes. The object of these pits is to bring ingots which may be cold, or nearly so, up to a suitable temperature for rolling to some smaller billet or bar. The temperature is important: it is normally about 1200 deg C, dependent on the type of steel and the shape being rolled, the essential point being that the ingot shall be thoroughly soaked and is as nearly as possible at the same temperature throughout. The ideal would be to measure this temperature in the centre of the ingot, but this of course is completely impracticable. A working compromise is arrived at by measuring the inside temperature of the pit, using one or more thermocouples, carefully positioned to avoid flame impingement and damage when ingots are charged or withdrawn. It is from this thermocouple installation that the temperature control is initiated by first controlling combustion air, to which is linked the fuel valve. This method is used to ensure that should there be a failure of air due to some external source the fuel also would be cut off. An alternative scheme is to arrange for control to be taken over if necessary by a thermocouple in the flue. If a condition should arise where the flue temperature has reached a maximum value, then automatic selection of the highest thermocouple will protect either section of the pit from excessive temperature. In addition to selective temperature control, the pressure in the pit must be maintained at some predetermined figure, which is usually a little less than 0·1 in. w.g. This calls for a sensitive pressure measuring instrument, generally of the inverted bell type, which is in turn responsible for controlling a damper in the outlet gas flue to hold the pit pressure stable. An interlocking switch coupled with whatever mechanism is used for lid or cover removal ensures that the fuel and air supply is shut off whilst the cover is off for ingot insertion or withdrawal. Air fuel ratios are readily adjustable and every endeavour is made to obtain maximum efficiency from fuel used. Soaking pits of this type are generally built in sets of four or six together, which enables the rolling mill to operate for long periods, continually withdrawing ingots of the right temperature without undue delays in the rolling programme.

Finally, it must be pointed out that none of the systems described will operate without skilled attention and maintenance, and it is vital to have a supply of clean, dry, compressed air. All these, together with good installation, will well repay the expense of the initial outlay.

Summary

An endeavour has been made to outline briefly how the numerous types of control apparatus can be utilized in the manufacture of iron and steel, commencing with the raw materials in the blast furnace, the making of steel in the open hearth furnace and the final rolling into a useful commodity, where temperature, pressure and flow control play a large part.

by **C. M. BURRELL, M.A., B.Sc., A.M.I.E.E.,**
& J. K. LUBBOCK, M.A., B.Sc.
Lecturers in Department of Engineering, Cambridge University

PART
2

What is control engineering?

THE FIRST ARTICLE presented the background of automation in relation to feedback control and emphasized the importance of feedback in control engineering. This second article deals with feedback systems in more detail, including the development of a simple mathematical theory, and the discussion of on–off systems.

Terminology

Although it is not our purpose systematically to cover all the definitions necessary for any discussion of automatic control, certain definitions are needed before we can proceed further. It might be thought that a standard set of mutually exclusive, universally used terms, already existed. Unfortunately this is not the case. Different words are used to convey the same meanings, and the same words are used with different meanings, in some circumstances because of the variety of uses, and of users, of automatic control. The British Standards Institution is at present concerned with the selection of a set of definitions common to all forms of automatic control, but these definitions are not yet available. Existing sets of British Standard definitions, relating to different groups of control users, are not sufficiently consistent for our purposes. Consequently we shall from time to time throughout the ensuing articles define such terms as are needed.

The feedback amplifier

The simplest feedback system is the feedback amplifier. This can take a great variety of forms, including electronic, pneumatic, hydraulic, mechanical, magnetic and most of these in combination. For our present purpose of deriving some properties of feedback systems, we choose the pneumatic amplifier. Fig. 1 shows a line diagram of the amplifier. The input and output quantities are air pressures. The input pressure operates a bellows and controls the flapper to nozzle separation. The nozzle is supplied, via a restriction, with fairly high pressure air at nominally constant pressure. When the flapper closes the nozzle the open-circuit output pressure is equal to the supply pressure, there being virtually no flow through the restriction. A very small movement of the flapper (of order 0·001 in.) away from the nozzle suffices to make the pressure drop at the nozzle small, and thus bring the output pressure to atmospheric. The curve relating output, or nozzle pressure to flapper position, for a typical practical case is shown in Fig. 2. The curve is, of course, non-linear, but as shown there is an approximately linear region. Let P_1 and P_2 represent the input and output pressures corresponding to a flapper position at the middle of the linear range. Let this flapper distance from the nozzle be X. We will denote deviations of pressure or distances from their mid-values by small letters. Let K_2 be the slope of the linear portion of the curve of Fig. 2.

Thus

$$K_2 = \frac{p_2}{x} \qquad \dots (1)$$

but x is related to p by another constant K_1, depending on the spring constant of the input bellows, the mechanical advantage of the linkage and the reaction due to the nozzle air flow. This last will be ignored, since it can be made to be very small by arranging the flapper to travel across the nozzle.

Hence

$$x = K_1 p_1 \qquad \dots (2)$$

The gain of the amplifier, constant over its linear range, is then

$$\frac{\text{Deviation of output pressure}}{\text{Deviation of input pressure}} = A = \frac{p_2}{p_1} = K_1 K_2 \qquad \dots (3)$$

In practice A can have a very large value, of the order of 100 000 or even greater.

We have found the pressure gain of the pneumatic amplifier

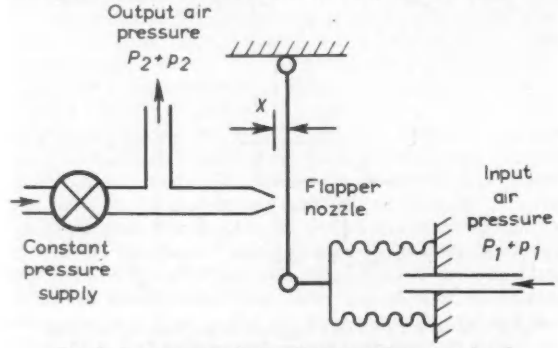


Fig. 1 A pneumatic device illustrates the principle of amplification

with no load at its output. In practice every amplifier operates into a load of some kind and indeed we define an amplifier as follows:

> An amplifier is a device capable of producing a higher rate of change of energy at its output (load) than is supplied to its input. An amplifier, therefore, must always have two inputs, one for information (usually on a low-energy carrier) and one for raw energy.

The term 'rate of change of energy' is used instead of power since power is normally used to mean dissipation, whereas many amplifiers are used to provide a high rate of change of energy in the load rather than a power output. (Examples are amplifiers feeding inductive loads such as the scanning coils of a television tube or the field coils of a d.c. motor. Neither produces a useful power output.) However, any amplifier will produce a power gain if it is operated into a suitable dissipative load. The pneumatic amplifier has a substantial gain in

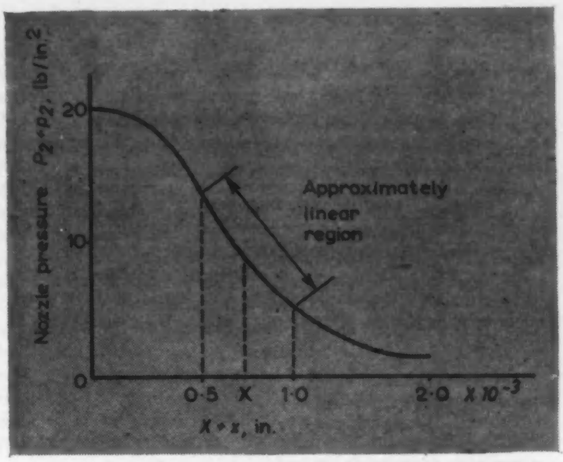


Fig. 2 In a flapper-nozzle system the relationship between nozzle pressure and flapper movement is nearly linear over a short range

the sense of this definition, although we have actually found the pressure gain for the steady state, or very slowly changing inputs, thus ignoring the energy storage at both input and output.

Feedback can be readily applied to the pneumatic amplifier and the benefits resulting demonstrated quantitatively. Thus in Fig. 3 the nozzle, or output pressure, is fed into the feedback bellows and the force developed is opposed by a spring therein, such that

$$x_2 = K_3 p_2 \qquad \ldots (4)$$

where x_2 is the movement of the flapper caused by a change in output pressure p_2 and K_3 is a constant of proportionality dependent on feedback bellows area, spring constant and the mechanical linkage.

Using equation 2 we obtain the net flapper movement

$$x = x_1 - x_2 = K_1 p_1 - K_3 p_2 \qquad \ldots (5)$$

but

$$p_2 = K_2 (x_1 - x_2) \qquad \ldots (6)$$

so

$$p_2 \left(\frac{1}{K_2} + K_3 \right) = K_1 p_1$$

and the net gain

$$N = \frac{p_2}{p_1} = \frac{K_1 K_2}{1 + K_2 K_3} \qquad \ldots (7)$$

The mathematical dependence of the various quantities in the system may be indicated on a diagram showing the paths of information flow. Physical quantities in the system are enclosed by circles, and the mathematical dependence of one quantity upon another is indicated by an expression or formula written beside the line joining the quantities. By definition all such lines are unilateral (i.e. convey information in one direction only, namely that indicated by the arrows upon each line). The dependence diagram for the pneumatic feedback-amplifier is shown in Fig. 4. From this diagram the mathematical equations can be written down immediately.

Properties of feedback

One effect of applying feedback to a high gain, non-linear amplifier, such as this pneumatic amplifier, is to improve the linearity at the expense of gain reduction. Thus if $K_2 K_3$ is very large we get

$$N \simeq \frac{K_1}{K_3} \qquad \ldots (8)$$

The gain is therefore independent of K_2 (shown pressure dependent in Fig. 2) and in so far as K_1 and K_3 are constant (independent of time, temperature and pressure), N is also constant.

This feedback system, in common with many others, also has the following distinct advantage. For large feedback, the effect of load change on output pressure is reduced by the factor $1 + K_2K_3$; we can see this as follows. If a large air flow demand is placed upon the amplifier by its load, then without feedback we can say that the flow through the restriction, situated before the nozzle, is given by

$$q + q_2 = \frac{p - p_2}{R} \qquad \ldots (9)$$

assuming that the law between flow q and pressure change p is linear. In equation 9

$p - p_2$ is the pressure drop across the restriction
q is the flow rate through the nozzle
q_2 is the flow rate to the load
R is a constant which depends on the restriction.

Hence

$$p_2 = p - R(q + q_2) = p - Rq - p_l \qquad \ldots (10)$$

where p_l represents an error in the output pressure due to loading.

In a feedback amplifier any error in p_2 is detected by the feedback bellows, and corrective action is applied to the flapper so that the error in p_2 is reduced. The dependence diagram with a load disturbance of magnitude p_l is shown in Fig. 5. From this diagram

$$x = K_1 p_1 - K_3 p_2 \qquad \ldots (11)$$

$$p_2 = K_2 x - p_l$$

$$x = \frac{p_2 + p_l}{K_2} \qquad \ldots (12)$$

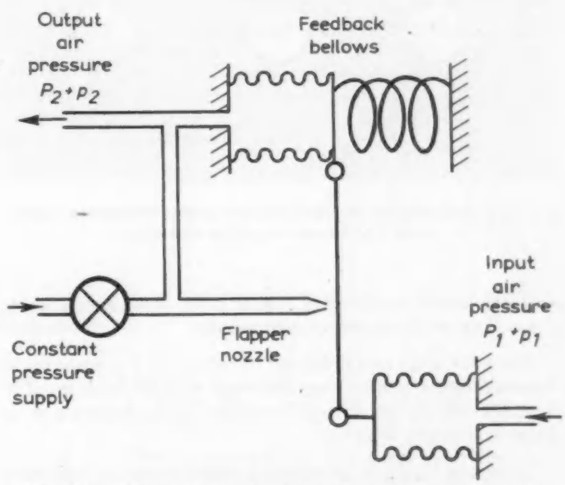


Fig. 3 An additional spring-loaded bellows adds feedback to the simple amplifier

Substituting (12) in (11) gives

$$\frac{p_2}{p_1} = \frac{K_1 K_2}{1 + K_2 K_3} - \frac{p_l}{p_1} \cdot \frac{1}{1 + K_2 K_3} \qquad \ldots (13)$$

Thus when $K_2 K_3$ is large the effect of p_l on the output pressure is only small and is $1/(1 + K_2K_3)$ times less than the effect on a system without feedback. This theory applies also to an electronic feedback amplifier, in which case we should describe this result as a reduction of *output impedance* by the use of feedback.

Some definitions

It is now appropriate to give formal definitions of certain terms already used.

A system is a collection of elements having an output

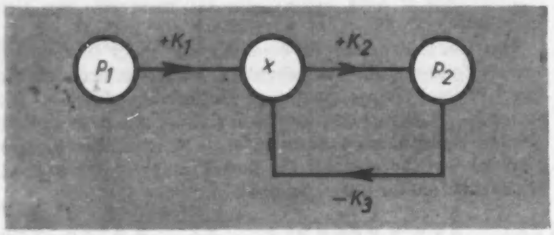


Fig. 4 Dependence diagram for a pneumatic feedback-amplifier

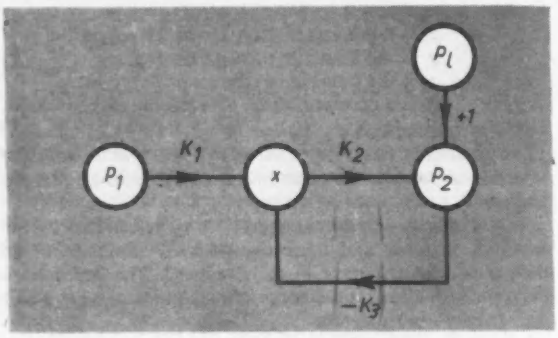


Fig. 5 Dependence diagram for a pneumatic feedback-amplifier with load

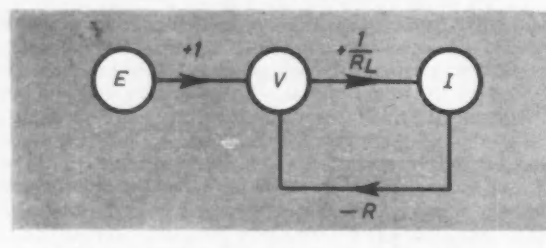


Fig. 6 Dependence diagram of a d.c. source of internal resistance R and e.m.f. supplying a load R_L

quantity which is related to one or more input quantities by some chain of mathematical dependence.

The error is the signal derived by subtraction of some linear function of the output from the input or some function of it. Usually, but by no means invariably, direct subtraction of input and output occurs.

A system is said to be *error actuated* if the output quantity depends upon some function of the error.

Feedback is said to be present if there exists transference of information from any point in the chain of dependence to an earlier point in that chain, *via a separate physical path specially inserted* for this purpose.

This definition of feedback, involving a separate physical path, is made on purpose to exclude systems having inherent regulation, i.e. the property of reaching a new equilibrium on the application of a disturbance. Inherent regulation can occur in any linear network which is bilateral, so if we define feedback to include inherent regulation the definition would be so general that it would be meaningless. An example is a d.c. source of fixed internal e.m.f. E supplying an output current to a load, via its own internal resistance R. The dependence diagram is shown in Fig. 6 and it is seen that transference of information from output to input occurs although not along a separate physical path. Physically, we can demonstrate that the system has inherent regulation since, if the load resistance is decreased, the current increases, thus increasing the voltage drop in the internal resistance and decreasing the current.

An *open-loop control system* is one in which the output is controlled by one or more inputs in a scheme of dependence without physically separate error actuation.

A *closed-loop control system* is one in which the output quantity is controlled by some function of an error generated by a physically separate feedback of the output quantity.

There are important cases not covered by the above definitions for open- and closed-loop systems, e.g. combined open- and closed-loop control systems. These will be dealt with as they arise.

The on–off system

In the analysis of the feedback amplifier two important assumptions were made:

1. That the system was linear.
2. That the system had no lags due to energy storage.*

It is seen from Fig. 2 that the first assumption is invalid except for a very small range of input flapper displacement. The second assumption is only true for slow rates of change of pressure. We will now deliberately consider these two effects.

A simple high-gain amplifier of the type described can be driven into non-linear saturation even for relatively small input deviations (p_1). From Fig. 2 we see that the output saturation pressures are zero and 20 lb/in². If the input pressure is significantly greater than P_1 then the output will be 20 lb/in² and if the input pressure is significantly less than P_1 the output will be zero. By making the amplifier gain approach infinity we can produce a device having only two output levels which do not depend in any way upon relative input amplitudes, but only on the sign of the deviation of the

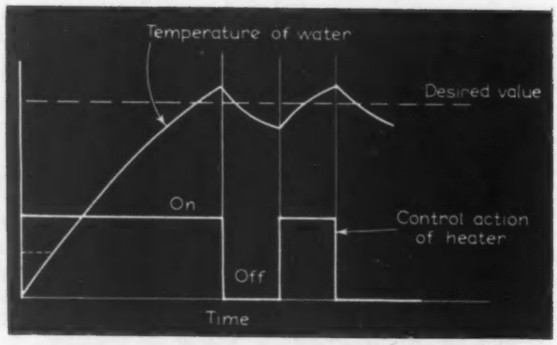


Fig. 7 In an on–off system the controlled variable oscillates about the desired value

input amplitude from P_1. Such a system is called an on–off system.

On–off systems are common in domestic application, e.g. thermostats on immersion heaters, electric ovens, electric irons, etc. In these appliances the current will be switched on to the heater when the temperature falls below a predetermined desired value and switched off again when the temperature rises above the desired value (hence the term 'on–off'). In an application of this kind the pneumatic amplifier is obviously inappropriate, and it is normal to use a bimetallic strip equipped with an electrical contact at its end, which acts as the temperature sensitive element and the on–off controller.

* Energy storage and its effects in a system will be dealt with in more detail in later articles.

The electric heater is a suitable example for the demonstration of the effect of a *lag* in the system. Consider an immersion heater; when the current is switched on it flows through the heating element and heat energy flows into the water. Owing to the heat capacity of the water and the tank, some time elapses before the water temperature reaches the desired value at which the thermostat switches off. When switched off, heat energy will be slowly lost to the outer space by conduction and although no load demands are made upon the system, in time the temperature will fall below the desired value and the thermostat will switch on again. The curves of system response and controller action, in the absence of load demand, are shown in Fig. 7 whilst a block diagram of the system is shown in Fig. 8. The energy storage due to the thermal capacity of the tank and its contents, combined with the finite rate of supply of energy via the heater, prevents the water temperature following the control action, and because of the thermal capacity of the heater itself it continues for a short time after the current is switched off.

An important characteristic of all on–off systems is that they tend to hunt continuously at an amplitude and frequency which depends upon the system lags; this is inevitable since neither of the two available controller actions by themselves can produce the desired output quantity.

In this and the preceding article, block diagrams have been used to show the physical layout of the systems under discussion. Unlike dependence diagrams, the block diagram shows not only information flow paths but also flow paths of material and energy objects.* Care is necessary to avoid confusion between these various flow paths since often the energy or material object acts as an information carrier over part of the information loop.

Summary

From the analysis of a feedback amplifier the gain equation is found to be

$$N = \frac{K_1K_2}{1 + K_2K_3} = \frac{A}{1 + A\beta}$$

where $A = K_1K_2$ is the amplifier gain before the application of feedback and β is a factor which depends upon the proportion of the output signal which is fed back to the input. By applying feedback across a semi-linear device, linearity is improved at the expense of gain; the error introduced by loading in a feedback amplifier is $1/(1 + A\beta)$ times less than in a similar amplifier of the same gain ; and provided the loop gain $A\beta$ is large compared with unity, the overall gain with feedback is determined almost entirely by β. By making β very stable against time, temperature variations, etc. the overall gain is stabilized.

The dependence diagram is an information flow diagram on which is indicated the mathematical dependence between all quantities in the system. The block diagram shows the physical layout indicating both information flow paths and material or energy flow paths.

An on–off controller can be considered as an infinite gain saturating amplifier. When it is connected in a feedback loop containing energy stores it oscillates continuously at a frequency and amplitude dependent upon the system lags.

To be continued

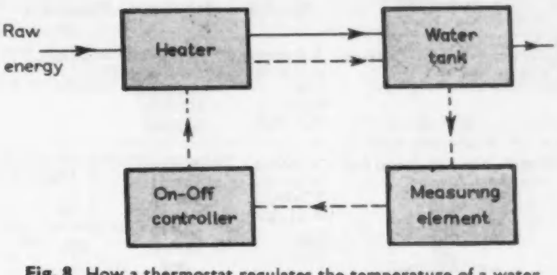


Fig. 8 How a thermostat regulates the temperature of a water tank. ——— Energy – – – Information

* cf. CONTROL, July 1958, pp 16–18.

LOOKING AHEAD

A diary for the next three months

AUG 18–23	*International Conference on Semi-Conductors.* See July p 31.
AUG 23–SEPT 2	*International Fair of Technics and Technical Achievements.* See July p 31.
AUG 27–SEPT 3	*120th Annual Meeting of the British Association for the Advancement of Science.* See July p. 31.
SEPT 1–7	*The Farnborough Air Show.* See July p 31.
SEPT 1–13	*International Conference on Peaceful Uses of Atomic Energy.* See July p 31.
SEPT 3–5	*Cryogenic Engineering Conference* in Massachusetts. Details from The Secretary, 1958 Cryogenic Engineering Conference, Dept. of Chemical Engineering, University of Colorado, Boulder, Colorado, USA.
SEPT 3–10	*2nd International Conference on Cybernetics.* See July p 31.
SEPT 15–26	Summer School in *Programme Design for Automatic Digital Computing Machines*, at Cambridge. Applications immediately to the Secretary of the Board of Extra-Mural Studies, Stuart House, Mill Lane, Cambridge.
SEPT 16–20	*International Symposium on Nuclear Electronics.* See July p 31.
SEPT 24–OCT 3	*Industrial Fuel Efficiency Exhibition.* Details from J. Baker, Esq, Dale Reynolds Publicity Ltd, 32 Finsbury Square, EC2.
OCT 13–18	*Congreso International de Automatica* in Madrid. Details from Professor J. Garisa Santesmases, Instituto de Electricidad y Automatica, Facultad de Ciencias, Ciudad Universitaria, Madrid.

COURSES

SEPT 30–MAR 24 '59	A course of 24 lectures on *Instrumentation and Telemetering* will be held at the Northampton College of Advanced Technology, St John Street, EC1. Details from the Dept. of Instrument Engineering.
OCT 8–MAR 18 '59	A course of 20 lectures on *Automatic Process Control* will be given at the Northampton College of Advanced Technology, St John Street, EC1. Details from the Principal.

LOOKING FURTHER AHEAD

MAY 25–29 '59	*International Convention on Transistors and Associated Semi-Conductor Devices.* Details from the Secretary, The Institution of Electrical Engineers, Savoy Place, WC2.

CONTROL 2 SURVEY A.C. SERVOMOTORS

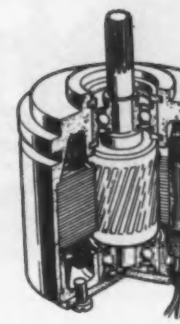
RATED PERFORMANCE

Manufacturer	Number	Description	Frequency, c/s	No. of phases	Ref. voltage, std	No-load speed, r.p.m.	Max. output power, W	Speed at max. output, r.p.m.	Control phase voltage
S. G. Brown Ltd *Shakespeare Street, Watford, Herts*	A.P.8040/1	all 6 pole	all 400	all 2	50	5 760	0·72	3 000	50
	A.P.8096	squirrel cage			25	7 300	1·1	5 000	25
	15A	induction			115	22 800	8·9	12 500	115
	SGB115	(15 A is			115	7 380	1·75	5 300	115
	A.P.8064	2 pole)			50	7 300	1·3	4 300	50
Elliott Brothers (London) Ltd *Lewisham, London, SE13*	7C1090/1	size 08	50			2 500			
	7C1123/1	size 11		all 2	26				20SP
	7C1090/2	size 08	60			3 000			
	7C1123/2	size 11							
	18B	size 18 squirrel cage	400	2	115	4 800			115SP
	18D								
	RWC-2405	size 24 squirrel cage	50	2	110	1300–1400			115 CT optional
	RWC-2407								
	RWC-2410								
	RWC-2414								
Evershed & Vignoles Ltd *Acton Lane Works, Chiswick, London, W4*	FAM	all induction	50/60	all 2	50	3 300	0·75		50
			400		115	24 000	2·8		115
	FT		50/60		50	3 300	1·8		50
	FY2		50/60		50	2 950			50
	FC74		50		50	2 750			50
	FZ20		50		50	2 800			50
Kelvin & Hughes Ltd *Barkingside, Essex*	KB620/01		50/60	2	115	2 800	5·7	1 600	115
Ketay Ltd *Eddes House, Eastern Avenue West, Romford, Essex*	100E2A/B	size 10	400		26	6 500			50/26
	101E2C/E /F/J	size 11	400		115	6 200			180/26 115/115
	105E1A/C	size 15	60	all 2	115	3 200			28/115
	105E2A6/C5	size 15	400		115	4 800			115/230
	105E2J	size 15	400		115	10 000			230
	108E1D	size 18	60		115	3 200			115
	108E2E	size 18	400		115	10 000			115
	108E2B/C	size 18	400		115	4 800			282/115
	113E1Y	size 23	60		115	3 300			115
Laurence, Scott & Electromotors Ltd *Openshaw Works, Manchester*		size 11 squirrel cage	400	2	115	10 000	1·43	5 500	115 or 58
Muirhead & Co Ltd *Beckenham, Kent*	08M10A1		400	all 2	26	6 500	0·144	3 500	26SP
	10M10A1		400		115	6 500	0·39	3 500	26SP
	11M10/A1								115SP
	A2				115				180SP
	A3	squirrel cage							40SP
	A4		400			6 200	1·1	4 000	26SP
	A5								32SP
	A6				26				26SP
	15M10A1		400		115	4 800	1·6	2 850	115 or 58SP
	1510M10A2						1·84	2 500	20 or 10SP
	18M10B1		400		115	4·800	3·0	2 700	115SP
	18M10B2				115	4 800			10 or 20SP
	E16A/1		50		50	2 800	2·62	1 500	50SP
R. B. Pullin & Co Ltd *Phoenix Works, Great West Road, Middx*	R-124-G	squirrel cage	400	2	26	7 200	0·45	3 700	26
	R-124-S								40CT
	RM.118-B								20CT
Smiths Aircraft Instruments Ltd *Cricklewood Works, Edgware Road, London, NW2*	071SCM/1	size 07 induction	400	2	26	9 000	0·28	5 000	26
	072SCM/2								20CT
	111SCM/1	size 11 induction	400	2	115	6 200	0·85	3 500	115SP
Sperry Gyroscope Co Ltd *Brentford, Middx*		size 11 induction	400	2	115	6 800	1·0	3 500	115CT or 20CT
Vactric (Control Equipment) Ltd *196 Sloane Street, London, SW1*	size 07	induction	all 400	all 2	26	9 000	0·23	5 000	26SP
	10	induction			26	7 000	0·45	3 700	26SP
	11	induction			115	6 200	0·95	4 500	115SP
	11	a.c. drag cup			115	2 200	0·26	1 100	115SP
	15	induction			115	4 800	3·0	2 700	115SP
	18	induction			115	4 800	4·1	2 700	115SP

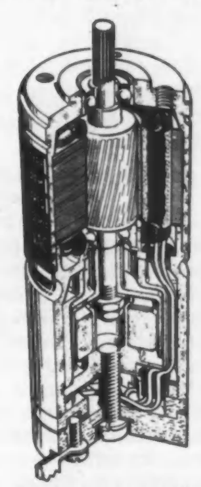
The second of our surveys deals with one of the most important elements in a servomechanism—the servomotor. We give details of a.c. motors of less than 100 W with separate control phase windings. Next month's survey will cover d.c. servomotors, tachogenerators and motors with built-on tachogenerators.

Claimed to be among the smallest in the world

STALL PERFORMANCE		MECHANICAL DETAILS		
Torque, g–cm	Input power, W/phase	Moment of inertia, g–cm²	Weight, g	Remarks and Special Features
47	4·3	6·2		The rotor is mounted on ball races, lightly pre-loaded by spring pressure. The 15A has a copper sleeve rotor mounted in a standard size cylindrical housing.
36	3·2	7·5		
132	20·3	2·35		
48	5·2	7·5		
39	3·6	7·5		
30	2·5	1·0	60	The winding is completely encapsulated and the magnetic materials are corrosion resistant.
55	3·6		120	
30			60	
55			120	
240	12·5	7		These two motors generally conform to Ministry of Supply Specification EL.1789.
170	10·0	4		
93·5		12·8		
137		18·3		
202		23·8		Holtzer-Cabot 24 size motors are designed for applications in industrial control.
296		33·0		
72	9·5	5·1	340	The principal features claimed for these motors are: a high starting torque and low inertia to give rapid acceleration; and a high efficiency enabling maximum power to be obtained using the small space available. The standard motors are wound for 50 V, 50 c/s, or 115 V, 400 c/s, but motors can be wound to order.
23·8	15·0			
172·8	12	12·2	510	
158·5	52	110·0	2600	
274	11	29·3	453	
432	16	49·5	910	
520	17	17	850	
21·6	3·1	0·46	41·0	These motors all have split control phases and the figures given are for them connected in series. They are manufactured by Norden Ketay Corporation USA, from whom Ketay Ltd can obtain development quantities. Ketay Ltd are working on the production in this country of a number of them. Gearheads and amplifier (magnetic and transistorized) are available if required.
43·2	3·5	1·07	127	
32·4	3·5	3·3	240	
104·5	6·1	3·3	207	
68·5	6·1	3·3	207	
169	18·0	3·5	346	
130		3·5	346	
223/169	9·2	3·5	346	
505	16	18·0	720	
47	5	6·04	156	
7·3	1·7	0·46	28·4	All the motors have two control windings which may be connected in series or parallel. The rotors are mounted on single row, ball journal bearings, grease lubricated.
20·0	3·0	0·46	41·0	
45	3·25 / 3·5	1·1	125	
104	6·1	3·1 / 3·03	226 / 256	
173	9·0	4	375	
290	10·5	150	900	
22	2·6	0·46	41	A range of transistor servo amplifiers and gear units are available for these motors.
8	2·5	0·18	35·4	The 07 motors are reported to be among the smallest in the world, with a diameter of [illegible] in. and a length of 1[illegible] in.
8	2·5			
45	3·65	1·1	120·5	
45	3·4	1·0	120	
9	2·3	0·15	26	The motors can also be supplied in a variety of voltages and in accordance with the Ministry of Supply Specification EL.1789, which requires normal operation for 1000 hours in the ambient temperature range − 65 deg C to + 85 deg C at altitudes up to 60 000 ft.
22	2·5	0·5	42	
44	3·5	1·0	110	
44	3·5	2·0	160	
104	6·5	3·5	200	
170	9·5	4·2	350	



Compact, precision built



Better system stability is achieved by a drag-cup servomotor

The following definitions have been used:

CT = centre tapped phase.
SP = split phase (the figures given in front of the abbreviation are for the phases connected in series)

These conversions may be useful:

1 oz-in. = 72 g-cm
1 oz-in² = 183 g-cm²

$$\text{Torque (g-cm)} = \frac{\text{Output power (watts)} \times 10^5}{1{\cdot}05 \times \text{Speed (r.p.m.)}}$$

Details of missile power packs are revealed by a lecturer at the NATO guided weapon course

MISSILES

the power to guide them

by **K. C. GARNER,** B.Sc. (Eng.), A.M.I.E.E., A.F.R.Ae.S.

Lecturer in Control and Simulation, College of Aeronautics, Cranfield

IN ORDER TO FLY a guided missile at all it is necessary to provide it with a certain total source of energy which must be stored within the airframe. This energy may be stored in one or more forms, but however it is stored it must fulfil two quite fundamental requirements, namely:

1. Propulsion—some of the stored energy must be converted into an acceleration along the missile's fore-and-aft axis.
2. Lateral and rolling accelerations—the remaining stored energy must be available to provide the necessary manoeuvres in the pitch, yaw and roll planes.

For a *guided* missile the latter is every bit as important as the propulsion aspect, as without it the missile has no capability to manoeuvre, or indeed to have any intelligence at all.

Given a source of energy, the missile system has to divert it into two main channels, electrical and mechanical. Fig. 1 shows this broad subdivision of energy in any missile. The following considerations are necessary in the design of auxiliary power supplies, and although they are each simple in themselves, a great deal of system study is necessary to achieve the necessary compromises between them and to integrate the total missile design.

The requirements for a power system

1. Sufficient power capacity for at least the time from launch to kill.
2. Lightest possible weight.
3. Smallest possible volume.
4. Adequate regulation of voltage, frequency and pressure.
5. Reliable starting.
6. Good environmental characteristics.
7. Reliable change-over characteristics when supplies are switched over from launcher to missile internal supplies.
8. Adequate storage and handling characteristics of the main energy source, suitable to the tactical requirements of the weapon.

The power capacity required of the primary energy source has to be considered for each individual missile. It will be governed by the tactical requirements, which in turn determine the all-up weight, size, duration of flight, internal instrumentation and actuator power. It is possible nowadays to make a quite accurate assessment of these factors, and

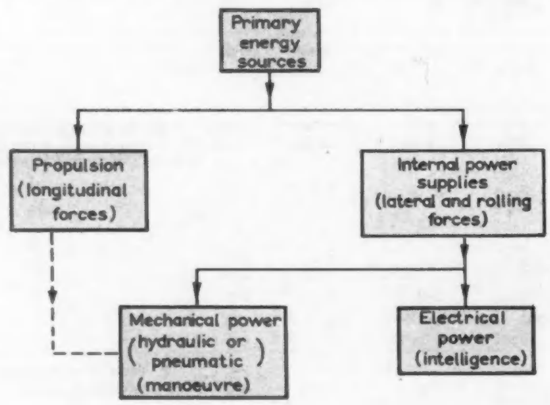


Fig. 1 The energy in a guided missile is distributed between propulsive and guidance requirements

on the basis of such figures the total energy requirement for the internal supplies can be estimated.

The weight and volume of the power supply are naturally of great importance, particularly in view of the fact that in missiles, as in aircraft design, the power supply designer is the Cinderella of the team and often tends to become squeezed out. The weight is primarily determined by the capacity required and the adaptability of an appropriate energy source compatible with the tactical requirements. For

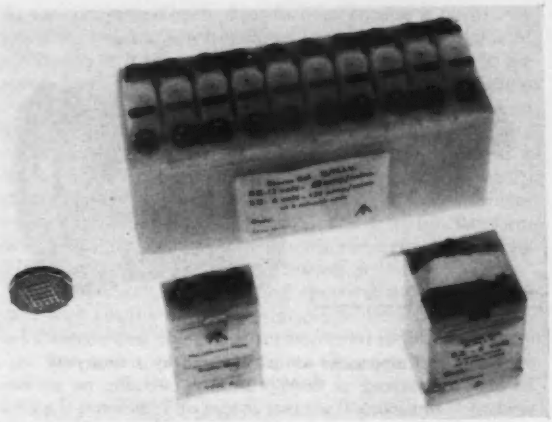


Fig. 2 Silver-zinc accumulators . . . have been highly developed in recent years

example, in a large missile hydraulic actuators are necessary, so that a completely electrical power source from batteries is insufficient. It is possible to reduce the weight by the judicious overrunning of components since missile durations are never more than minutes long. This technique is limited, however, if prolonged pre-flight tests are accepted. The volume occupied by internal power supplies is also determined by similar factors, and it should be mentioned that the ability to distribute both the weight and the volume is a distinct advantage when considerations of the position of the missile centre of gravity and space availability are important. Some systems are better suited in this respect than others.

The requirement for adequate regulation, particularly of electrical supplies for both voltage and frequency, is determined by the individual specifications of the guidance and control equipment. These requirements are usually quite stringent (e.g. better than 1 pc of nominal for voltage and frequency), and there is room for considerable compromise here between the 'suppliers' and the 'users', with mutual advantage. Where magnetic amplifiers are employed the harmonic content must also be considered.

As will be shown later, many power packs are driven from thermal sources of energy, which require some form of

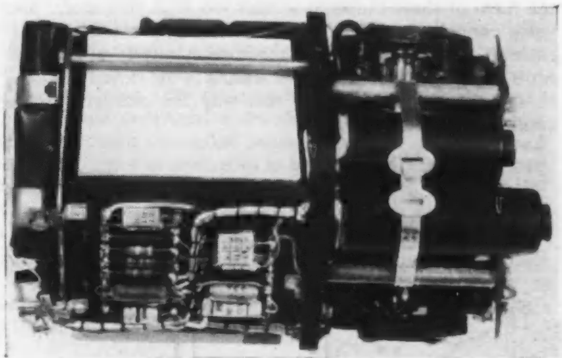


Fig. 3 A rotary-convertor for a small missile. It works from a battery and has a built-on regulating circuit

initiation. Most missile supplies must be fully operational within a matter of seconds, and considerable development has been devoted to this. Almost without exception, it is essential to provide launcher supplies immediately before firing to warm up valve heaters, run up gyro wheels, etc, and also to facilitate pre-flight checks. The latter is particularly true of research test vehicles. The change-over phase is highly critical since only a second or two remains before launch, and it is essential that no untoward transients occur due to mismatched voltages or frequencies, or to any discontinuity of supply at this instant. An important design feature concerning this aspect is the minimizing of power entries into the missile, i.e. the reduction to a bare minimum of the so-called 'umbilicals'. This not only increases the probable reliability but can greatly simplify the launcher layout.

The exacting conditions prevailing in a missile during its trajectory apply to all flight components including the power supply equipment. The main factors are well known, the most significant being the high sustained accelerations, vibration and altitude effects. As far as internal power supplies are concerned, high altitudes restrict the use of voltages much in excess of 400 V, make commutation difficult, and most important of all, cause difficulties in cooling. Temperature rises in the generating plant are difficult to control even with

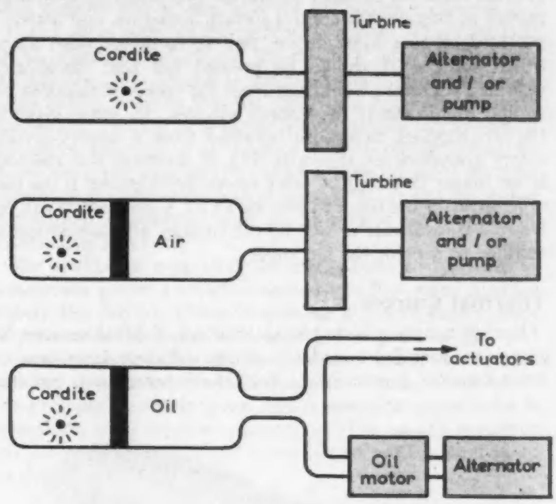


Fig. 4 Three ways in which thermal energy can be used to produce internal power supplies

a source of cooling air, owing often to the proximity of the thermal power source and/or the propulsion motor, and to kinetic heating. In addition the ground environment must be considered, and the primary energy source in particular must store well and be operational at the shortest possible notice.

Energy sources

The energy sources for internal supplies fall into three main categories: (1) electrical sources; (2) thermal sources; (3) pressure sources. One or more of the sources may be present in any particular missile, although all hydraulically-actuated weapons will be powered by categories (2) or (3) at least.

Durable and compact stacks of dry-cell primary batteries have been developed for missile applications. However, such an energy source alone is suitable only for very short duration missiles of the anti-tank or air-to-air interceptor types, having a time of flight of 10 to 20 seconds at the most. They have a reasonably good shelf life and they have the special advantage of possessing good stowage properties. They can be stacked to form various shapes and even separated into various sub-units for installation in the small type of missile for which they are best suited. A more important component is the secondary cell or accumulator, the chief advantages being the facility for recharging and the higher capacity per unit weight and volume compared with primary cells. A typical guided missile accumulator is the silver-zinc cell, some examples of which are shown in Fig. 2. These have been

highly developed in recent years, largely by Henri Andre in Paris, and Venner Accumulators in the UK. It is quite possible to produce a 200 ampere-hour battery weighing only 5 lb 9 oz. They can be made fully aerobatic since only a small amount of free electrolyte is necessary, and because they have no tendency to boil at low pressures they are satisfactory for use at extreme altitudes. A typical cell in normal production having a lower rating than those developed specifically for missile use has the following vital statistics: 32 Ah/lb; 48 Wh/lb; 2·02 Ah/in^3; 3·04 Wh/in^3.

Solar cells have been greatly popularized in recent months, mainly owing to the advent of artificial satellites for which they are highly suitable. For guided weapon use they are of little importance as yet, particularly since they would restrict a missile powered in this way to daylight operation only. Electric batteries provide an attractive way of providing h.t. and l.t. supplies with great simplicity. They cannot provide sufficient capacity to operate pneumatic or hydraulic pumps to energize the control surface actuators, and battery-powered missiles must derive their servo power from additional sources. It should be pointed out that electrically operated actuators would not meet the speed of response or torque requirements of modern missiles. In some systems the h.t. supplies have been obtained from a battery-driven rotary convertor as shown in Fig. 3, although this method is no longer favoured. A more recent development is the use of a transistor oscillator to provide an a.c. supply which can be fed to a transformer to step up the voltage, and subsequently rectified to provide the h.t. supply.

Thermal sources

For all but the shortest range missiles, thermal sources of energy are required in order to obtain sufficient duration and servo-actuator power. Many fuels have been tried, but the tendency at the present time is to use either cordite or the more recent application of mono-fuels such as iso-propyl-nitrate (IPN). Cordite is a very convenient primary fuel, capable of a wide range of burning characteristics according to the mix and the shape of the charge. Being solid it is easily handled and it has the advantage of being in quantity production; furthermore it presents no new difficulties to Service personnel who are already quite familiar with its properties. Slow burning types are used for missile systems. The main disadvantage is the 'dirty' products of combustion containing partially burnt cordite and other debris which complicate its use with the subsequent power-conversion equipment. Also the burning rate is somewhat difficult to control, which implies a difficult regulation problem. Some typical power conversion systems are shown in Fig. 4.

The two fundamental components of all thermal systems are a turbine and a pressure vessel of some kind. In the case of the hot gas system the working fluid in the turbine is the combustion gas. The cordite is ignited and the turbine rotor drives an alternator or a hydraulic pump or both. Regulation of the supply frequency is achieved by restricting the inlet gas flow to control the turbine speed. In this case the gases are heavily contaminated with debris and the normal variable-port valve would soon seize up. One interesting method of overcoming this, due to the English Electric Co, is to control the flow using a tappet-type valve which is in continuous oscillation, so that the gases are admitted to the turbine in the form of short bursts at a relatively high frequency. The valve continually closes on to its seating, providing a self-clearing action. The control mechanism merely adjusts the ratio of the time of dwell on the seating in the closed position, to the time of opening. In this way the *average* flow is controlled satisfactorily.

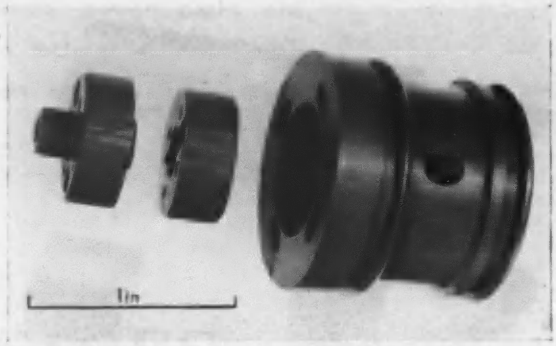
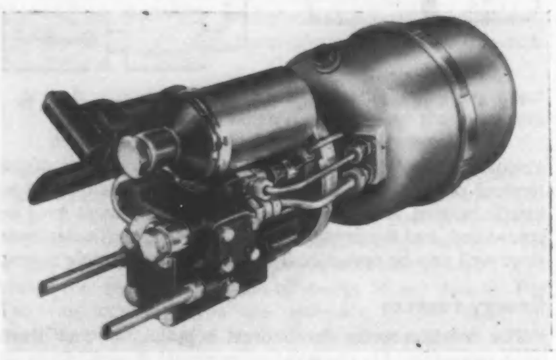


Fig. 5 Compressed air is regulated by a rotary-slit throttle valve



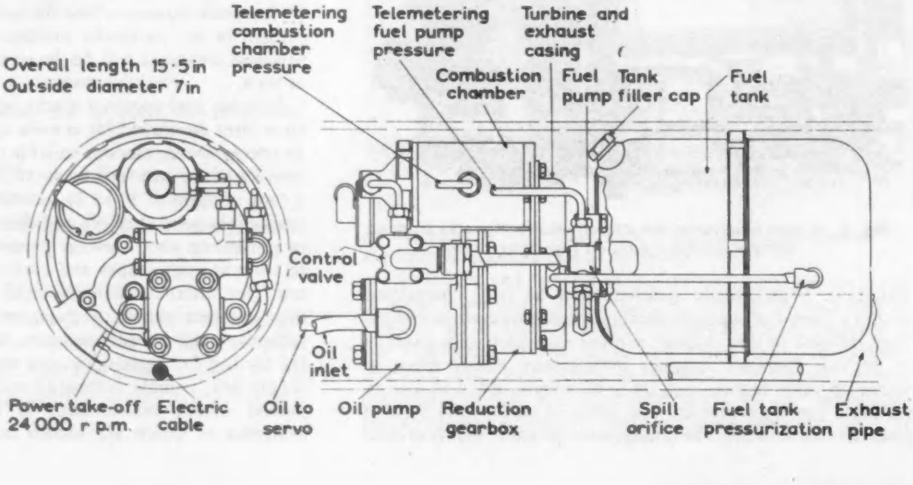


Fig. 6 This hydraulic power pack for a guided weapon uses IPN as the primary energy source. It develops 20 h.p. and is governed on the overall speed range to within 5 pc both on and off load

In the cordite-compressed air-turbine, cordite is burnt in a cylinder in which a piston is caused to compress a volume of air, nitrogen or helium, which is then the working fluid in the turbine. In this case the gas is clean and can be controlled by more conventional valves. One such valve is shown in Fig. 5; this has been designed by de Havilland Propellors for use with a fast rotary torque-motor. Instead of gas as a working fluid, hydraulic oil can be used on the secondary side of the piston, so obviating the necessity for a turbine-driven hydraulic pump to provide the actuator supplies. Efficient oil filtering is imperative since some cordite gas may get blown past the piston during operation.

All the methods of generating electrical and mechanical power with cordite apply in principle to IPN systems, with the difference that there is a further controllable parameter in the fuel flow into the combustion chamber. With suitable metering an effective control system to govern the rate of burning is possible. This means that the fluctuations in turbine speed can be made less dependent on the thermal source.

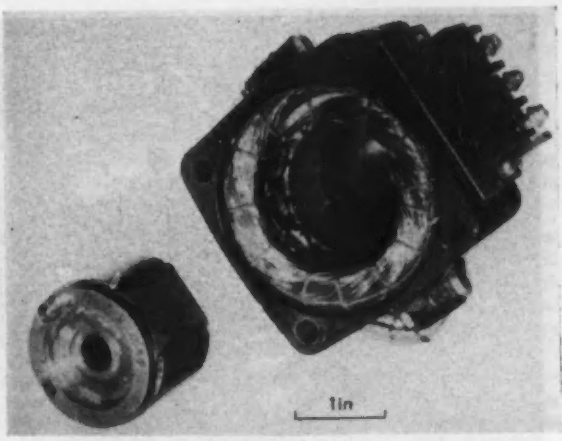


Fig. 7 A simple and rugged inductor alternator

Some developments using IPN have come from the Plessey Co, who have produced a hydraulic guided missile power pack, exhibited at the 1957 SBAC show at Farnborough. The Plessey hydraulic unit shown in Fig. 6 drives a pump through a reduction gear box, the power output being controlled by a fuel-metering valve according to the hydraulic load demands. This unit is capable of providing 20 h.p. at pressures up to 4500 lb/in^2 and weighs only 16 lb. The Plessey Co is also developing IPN systems for electrical outputs up to 7·5 kW, and combined hydraulic-electrical units. IPN is a relatively cheap mono-fuel available in large quantities, and can be regarded as analogous to kerosene or petrol as regards handling and general safety precautions*. Its chemical formula is $(CH_3)_2CHONO_2$ and has a flash point of 53° F (Abel closed cup). It can be stored in steel tanks although it corrodes this metal at a very slow rate requiring a six-monthly check. Commonly used synthetic plastics are suitable as sealing materials, and its properties are in general quite suitable for Service applications.

Pressure sources

There are two main methods of obtaining pressurized gas without thermal sources. The first is the use of ram-air. The second is simply to provide a compressed gas cylinder. Strictly, ram-air is the result of the conversion of the propulsion energy into kinetic energy. It is very simple, requiring nothing more than an inlet, generally at the nose of the missile, and suitable piping to duct the air to the required places. In general this method is only suitable for very short range missiles and is used only for the actuator pneumatics, batteries being used for the electrical supplies. There are two serious disadvantages. First, the missile's drag is increased, and secondly, it is difficult to design an efficient intake at high angles of incidence, so that the supply is a function of missile manoeuvre. The use of a moving-wing missile would reduce this effect although it is unlikely that anything would be gained since the wing servos would require far more air than conventional control-surface actuators. It should be noted that ram-air is available after the propulsive main motor or boosts have burnt out.

* See 'The properties of normal propyl and iso-propyl nitrates'. ICI Nobel Division, 28th May 1958.

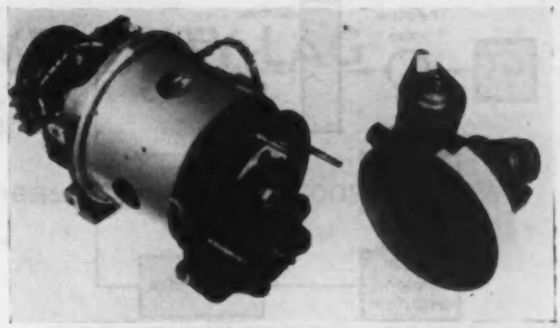


Fig. 8 Gas flow into the turbine on the right is converted into electrical energy by an inductor alternator

The method of containing an energy store in the form of compressed gas in a vessel is obvious. In fact many missiles require this facility, if not to provide a power supply, then to pressurize the liquid fuel tanks. The good weight and volume characteristics of the pressure vessels have been achieved by ingenuity in their shape and choice of materials. For example in one instance, the pressure-reducing valve is housed inside the cylinder to save space. The use of nitrogen or helium in preference to air is mainly to reduce the risk of accidental fires.

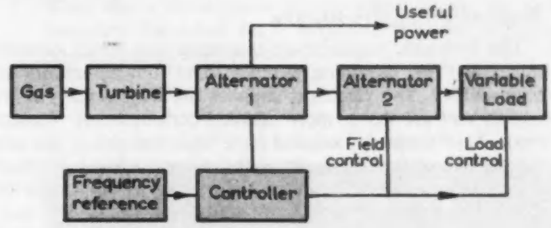


Fig. 9 The speed of a turbine may be controlled by this load-torque method

It can be seen from the foregoing sections that there is a reasonable, if limited, choice of primary sources of energy. The components which convert the power into hydraulic or electrical supplies are becoming fairly standardized in form, if not in size or performance. The main components are the turbine and the alternator. Different missiles have different turbines since obviously the power requirements differ. The general trend is towards the axial-flow impulse-turbine having a rotor speed of anything up to 50 000 r.p.m. Such speeds are normal to such turbines if any sort of efficiency is to be expected. A typical conversion efficiency is not usually more than about 20 pc. Generally the rotor diameter is about 4 to 8 in.

The most common machine in general use is the inductor alternator. It possesses many attractive features for missile application and an example is shown in Fig. 7.

A soft-iron yoke carries the field winding and the output winding. Rotating between the pole pieces is a soft iron armature. The field winding carries a direct current to energize

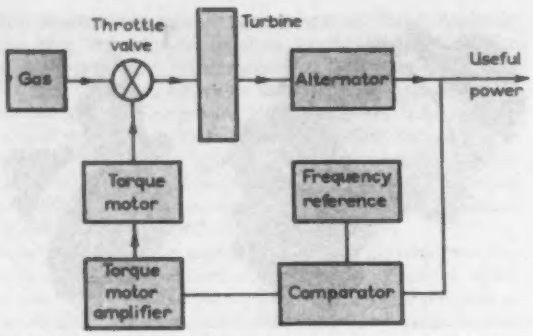


Fig. 10 A frequency regulating system for a turbo-alternator supply

the machine and is often boosted by a permanent magnet inserted in the appropriate sense in the yoke. As the armature rotates the air-gap changes, so varying the reluctance of the magnetic circuit. This causes an induced potential across the output coil at a frequency related directly to the armature speed, the number of poles and the number of salient teeth on the armature. The desirable features of such a machine are ruggedness, the absence of slip-rings or commutator and the facility with which relatively high frequencies of the order of thousands of cycles can be generated. Missile supplies are required at these higher frequencies to reduce the weight and size of inductive components. Somewhat lower frequencies are required where synchronous motors are installed in a missile to simplify the motor design. Any required frequency is easily obtained by the appropriate choice of the parameters mentioned above. One slight disadvantage is the relative inefficiency of this type of generator over a more conventional machine, but some improvement can be achieved by suitable reactive loading using capacitors to improve the power factor. Three-phase machines are generally used for their better power-weight ratio over single-phase machines of similar capacity.

Regulation of the supply

The hydraulic supplies are regulated in a fairly conventional way by providing a relief valve and sometimes an accumulator. The electrical supplies are considerably more critical and are worth more detailed consideration. Various methods of frequency control have been and are in use and the control of turbine speed is the common factor in them all. There are two ways of controlling this speed, either by metering the working fluid or by varying the rotor shaft load. The latter method is comparatively simple and is described for interest, although it has not met with much favour because of the weight penalty and the slow response involved. Fig. 9 is a block diagram of the scheme, where the generated frequency is compared with a reference to provide an error signal which varies either the excitation or the load of generator 2. In this way the turbine speed is altered to the desired value. Fig. 10 shows the more conventional way of speed control where the valve is in effect a proportional control on the gas flow into the turbine. The error signal is derived as before. The most usual frequency reference is derived from two tuned circuits whose resonant frequencies are displaced either side of the required nominal frequency. The error signal, so derived, is amplified and applied to the differential coils of a torque motor to which the throttle valve is coupled. A typical torque motor is the type developed by A. E. Laws at RAE Farnborough and now used extensively in various forms in guided weapons. Such a motor, if coupled to a suitable valve, can operate up to a corner frequency of 30 c/s with comparative ease.

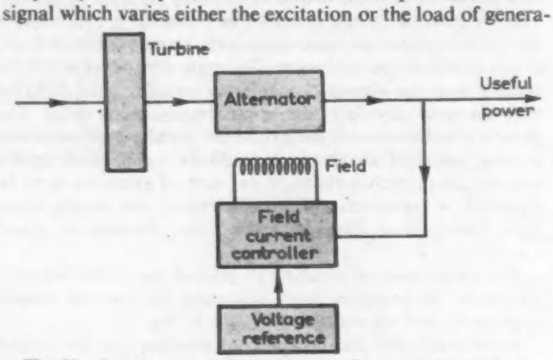


Fig. 11 A voltage regulating system for a turbo-alternator supply

The control of supply voltage is generally achieved by controlling the exciting field of the inductor alternator as shown in Fig. 11. Variations in the generator voltage and frequency are caused both by load variations and by turbine speed changes, so that there may be a considerable cross-coupling between the frequency controller and the voltage regulating loop, and due attention has to be paid to the mutual stability of these loops.

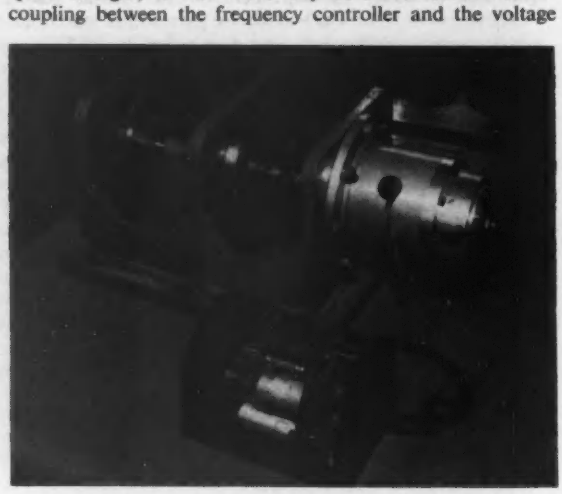


Fig. 12 Inductor alternator test rig used on the NATO guided weapons course, showing the packaged voltage and frequency stabilizing unit

With the rapid change of tactical requirements for guided weapons, it is most hazardous to guess whether any particular system will predominate in future missiles, although it is safe to assume that thermal systems will continue to be developed extensively in the next few years, particularly using monofuels such as IPN.

It is also likely that considerable standardization of components will take place now that production weapons are becoming available, as opposed to the preponderance of rather *ad hoc* test vehicles of previous years.

Summary

The power required for a guided missile can be divided into that required for propulsion and that which is necessary for flight control. The article deals with the latter aspect and the main points it discusses are as follows:

1. The requirements of a power system, including consideration of capacity, weight, volume, starting regulation and environmental characteristics.
2. Electrical, thermal and pressure energy sources for internal supplies.
3. The conversion of primary sources of energy into electrical or hydraulic supplies.
4. The regulation of converted supplies.
5. Future trends.

2-TIME-CONSTANT VELOCITY-LAG SERVOMECHANISMS

A new simple method of measuring the time-constants

by J. H. WESTCOTT, B.SC. (ENG.), PH.D., A.M.I.E.E.
Imperial College, London University.

Here is a new practical method of finding the time-constants of a 2-time-constant velocity-lag servomechanism. This type of servomechanism is typified by a simple position-control mechanism in which an error-actuated amplifier feeds a field-controlled d.c. servomotor with separate armature excitation.

The open-loop transfer function is of the form

$$\frac{C}{E}=\frac{k}{p(pT_1+1)(pT_2+1)}$$

where C and E are the transformed values of the controlled variable and actuating signal respectively and k has the dimensions sec^{-1}, owing to the integration in the denominator.

A particular system can be represented by fixing the two quantities T_1 and T_2, and the values of these uniquely define the behaviour of the system. Thus in principle we can determine T_1 and T_2 by two properly chosen measurements. The two measurements chosen for the present method are made when the system is connected as a closed-loop system; we turn up the amplifier gain until the system *just* oscillates and then record the values of the gain k_1 and the angular frequency ω_1 of the oscillation. We can make these two measurements with only a protractor and a stop watch. To measure k_1, one essentially has to compare angular displacement in the error channel and angular velocity of the output shaft, under open-loop conditions.

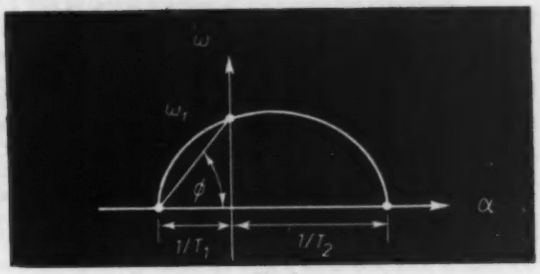


Fig. 1

A simple geometric construction now enables the two time-constants of the system to be found (Fig. 1). Draw an α-axis horizontally and an ω-axis vertically. Mark off ω_1 to some suitable scale along the positive ω-axis. Draw a line through $(0, \omega_1)$ such that it intersects the negative α-axis at an angle ϕ, where $\phi = 2 \arcsin(2\omega_1/k_1)$: this intersection point gives the reciprocal of the first time-constant T_1 say, on the same scale as was used for ω_1 on the ω-axis. Now describe a circle, with centre on the α-axis, passing through this intersection point and ω_1. Then the α co-ordinate of the point where the circle intersects the α-axis for a second time is the reciprocal of the second time-constant T_2.

THEORETICAL PROOF OF THE CONSTRUCTION

The open-loop transfer function is

$$\frac{C}{E}=\frac{k}{p(pT_1+1)(pT_2+1)}$$

The closed-loop transfer function is

$$\frac{C}{R}=\frac{C/E}{1+C/E}$$

where R is the transformed value of the reference input. Thus the new modes occur where $C/E=-1$, i.e. where

$$\frac{k}{p(pT_1+1)(pT_2+1)}=-1$$

From the test measurement we know that at gain k_1 one pair of modes is oscillatory at angular frequency ω_1, so that the following holds:

$$\frac{1}{j\omega_1(j\omega_1T_1+1)(j\omega_1T_2+1)}=-\frac{1}{k_1}$$

or rearranging

$$\frac{1/T_1}{\left(j\omega_1+\frac{1}{T_1}\right)}\,\frac{1/T_2}{\left(j\omega_1+\frac{1}{T_2}\right)}=-\frac{j\omega_1}{k_1} \quad . . . (1)$$

A geometric interpretation of this equation is shown in Fig. 2. Considering the moduli of the two vectors in Fig. 2, we have

$$\cos\theta \,.\, \cos\phi=\frac{\omega_1}{k_1} \quad . . . (2)$$

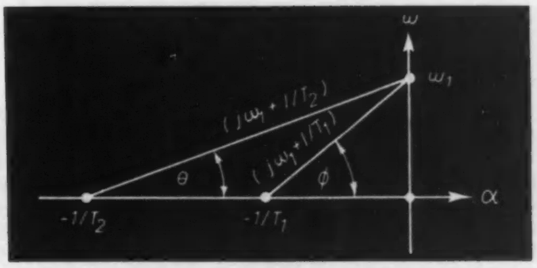


Fig. 2

from the positive phase relation, as defined in (1), we have

$$-\theta-\phi=-\frac{\pi}{2} \quad \text{or} \quad \theta+\phi=\frac{\pi}{2} \quad . . . (3)$$

Thus $\cos\theta=\sin\phi$.

Substitution of this in (2) gives

$$\sin\phi\cos\phi=\frac{\omega_1}{k_1}$$

But $\sin\phi\cos\phi=\frac{1}{2}\sin 2\phi$

Thus $\sin 2\phi=\frac{2\omega_1}{k_1}$ or $\phi=\frac{1}{2}\arcsin\frac{2\omega_1}{k_1}$

Therefore if we swing over one vector in Fig. 2 to make the same angle with the positive real axis, we have a right-angle between the vectors at the point (o, ω_1). This proves the construction.

Numerically controlled tools can lower your machining costs

Last month David Williamson explained the philosophy behind the Ferranti system of numerical control of machine tools and discussed the system from the user's viewpoint. He described the computer and the control unit in general terms. In this second and concluding part of the article he goes on to consider the design of the machine tool itself, in the light of requirements for successful computer operation and he gives a brief economic discussion of computer and hand control. We show here a picture of a typical vertical milling machine fitted with Ferranti numerical control (Fig. 7)

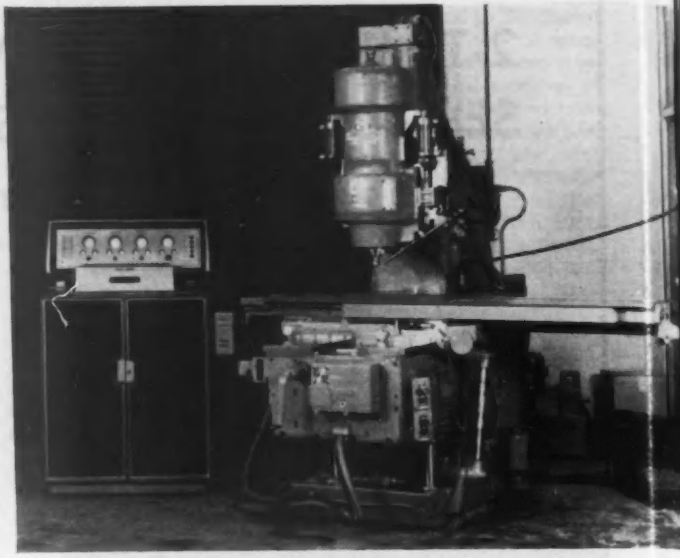


Fig. 7 A Ferranti console (approximately 60·5 in. high × 39·5 in. wide × 40·5 in. deep) controls this Kearney and Trecker vertical milling machine

COMPUTER CONTROL OF MACHINE TOOLS

the second part of an article describing the Ferranti system

by **D. T. N. WILLIAMSON**

Head of Machine Tool Control Department, Ferranti Ltd, Edinburgh

3. THE MACHINE TOOL

3.1 Mechanical construction

Machine tools in current use are far from being ideal subjects for precise electronic control. The design of their slideways and transmission has evolved only slightly over the past fifty years, possibly because the existing standards were considered to be satisfactory for hand operation. Machine tools, such as transfer machines, designed for continuous production work use the same basic principles but are more generously proportioned. The degree of friction and stiction, play and backlash which is present in such slides, or which develops during life, is such as to render their control by means of servomechanisms difficult, though by no means impossible.

It would be a great advantage, however, for reducing servo power requirements and achieving greater long-term accuracy, if certain precepts were considered at the design stage. The basic requirements for the machine tool associated with a numerical control system are:

a. *Long life and high production rates.* It is important to the economy of numerical control systems that the tool should be kept in action for long periods and that it should have the highest possible metal-removal rate whilst it is operating. This means that machines must be of rugged design, comparable with high-production transfer machines.

b. *High intrinsic long-term accuracy of the spindle, slide bearings and slide position measuring system.* It is insufficient for the machine to perform satisfactorily while new—it must continue to maintain its performance under intensive shop production conditions.

c. *High drive and structure stiffness.* This minimizes deflexions and vibrations.

d. *Low and consistent slideway friction.* This conserves expensive servomechanism power and increases stability margins.

e. *Slideways and transmission protected from damage by dirt, chips and coolant.* Frequent maintenance is thereby avoided.

Machine tool engineers will recognize that very few present-day machine tools could approach such a specification.

3.1.1 Slideways

The design of rigid friction-free slideways can be accomplished by two methods:

a. The use of rollers or other kinematic or pseudo-kinematic supports.

b. The flotation of the slide on a pressurized fluid film (*hydrostatic slides*).

The first method has been used successfully in jig borers and copying machines up to quite high capacities, and also to a higher degree in woodworking machinery and light-alloy milling machines. There is a current prejudice amongst machine tool manufacturers that this method severely restricts the load-carrying capacity of the slides, although it is doubtful whether there is much substance in this. Undoubtedly the quality of surface of the track has to be high in order that the load shall be equally shared by the rolling elements, and it may be that this impression was gained on machines which had not been so finished. The use of pressurized metered-flow oil slides has been proved in a machine tool, designed jointly by the Fairey Aviation Co Ltd and Ferranti Ltd. In this large 25 ft × 7 ft column-type milling machine, which has a 100 b.h.p. cutting head, the column, weighing 8.5 tons, and all other slides are floated on a film of oil maintained by a small pump unit in a manner fully described elsewhere (*3*, *4*). By

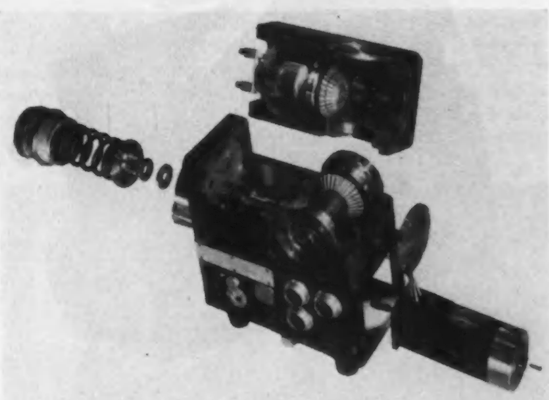


Fig. 8 Exploded view of a standard Ferranti double-train backlash-free reduction gearbox

careful design of the oil feed system, very high stiffness can be maintained; and, of course, the slides are almost entirely free from friction, what remains being viscous friction, which is a desirable parameter in a servomechanism. Two very great advantages of this system, apart from the obvious ones, are that the surface finish of the slideways need not be high, because of the clearance of the oil film and that wear is non-existent. Since the same precepts are followed in the design of the spindle bearings of the machine, except that air is employed as a fluid instead of oil because of its lower viscosity, this machine will be as good in fifty years' time as it is today, the only elements subject to wear being the transmission gears which are easily replaceable. Even on these, substantial wear could be tolerated because of the backlash loading methods employed throughout.

The use of air-bearing slides for machine tools is currently being investigated by the Mechanical Engineering Research Laboratory, East Kilbride, but their use seems likely to be restricted to small machines because of the large compressor power requirements. Oil appears to be a more suitable fluid, the disadvantage being that provision must be made for its collection, filtration and recirculation.

The important point about such designs is that they are not more expensive than conventional designs and may even be cheaper, which, in conjunction with indefinite life, makes it very likely they will eventually be adopted as standard.

3.1.2 Transmission stiffness

Where machine tools are driven by rotating servomotors, the transmission is almost invariably by means of a leadscrew or rack and pinion. The use of recirculating ball screws to overcome the low efficiency due to friction on conventional Acme threads has now become commonplace for small controlled tools, and, in the larger gantry and column machines, the rack-and-pinion method of drive takes over when a screw can no longer provide the required transmission stiffness. Worm drives have been used, but these are to be avoided because of their low efficiency and non-linearity.

3.1.3 The backlash loading of transmission elements

If an external measuring system is employed on the controlled machine tool, the linearity and overall accuracy of the transmission become of secondary importance, but the presence of high levels of backlash, particularly as these levels are not usually static, can seriously affect the performance of the servomechanisms. Many methods of removing backlash are currently in use in mechanisms. In Ferranti practice, backlash is removed from a recirculating ball screw and nut by the provision of a pair of nuts, one being taken as reference, with a compression spring (usually a pile of Belleville washers) between them, tightened up with a kinematic lock to give the desired value of pre-load.

The driving motor requires to be coupled to the transmission by means of a reduction gearbox so that it is matched to the load. This gearbox is a very important element in the servo loop and requires to be designed so that it reflects minimum inertia back to the servomotor, and has a suitably high working stiffness under all conditions with zero backlash. Fig. 8 shows an exploded view of a standard Ferranti gearbox designed to give these features. It consists of a double gear loop, formed by hardened and ground gears, from the servomotor shaft to the output bevels, which are split and can be assembled in any one of four alternative output positions. The two trains are loaded against each other up to the full torque capacity of the gearbox by means of a pair of helical gears with opposed tooth angles, axially loaded by means of a compression spring. Each side of the gearbox may drive or idle, depending on the direction of rotation, a method which gives the highest transmission efficiency. Extension units are available which convert this gearbox into a rack drive system, in which the twin drives are separately extended to pinions which engage on the rack, the pre-load then being applied right through from the motor shaft to the rack.

3.1.4 Cutter heads

The design of cutter heads, although it is not directly a control problem, is very important in a controlled machine tool, because, in addition to the obvious need to achieve high cutter horse-power to give high rates of metal removal, the bearing and power transmission system should have very low levels of vibration in order to obtain good surface finish and long cutter life, especially with hard metal or ceramic cutters. The avoidance of induced torsional vibration at harmonics of the cutter impact frequency is of prime importance, although it appears to have received scant consideration in the past. The use of pre-loaded bearings and the design of air- and oil-pressure bearings are being investigated.

It is essential to keep the development of cutter heads closely following the development of new cutter materials, so that maximum use can be made of their properties and the production rates of machines can be raised as swiftly as possible.

Although hitherto the most notable application of computer controlled machine tools has been in milling, the foregoing design considerations are just as applicable to turning, shaping and grinding machines to which the control system

is now being applied. The ultimate accuracy obtainable depends, of course, on the cutting process, and neither are the fundamentals of metal cutting well understood at present, nor is the knowledge which exists widely disseminated. In milling, the deflexion and deformation of the cutting tool and the material under the cutting stresses make the achievement of accuracy better than 0·001 in. somewhat uncertain.

3.1.5 Structural considerations

It is very difficult to keep the natural frequencies in large machines high by conventional methods of construction, particularly where there is considerable compounding of slides with resulting loss of stiffness and accuracy. As multi-axis machines will be necessary to make full use of numerical control techniques, this is an important aspect of design; it is imperative to investigate the design of machine tool structures with a view to achieving the highest stiffness and maximum freedom from resonance with minimum weight of material, and particularly the possibility of light-metal fabricated construction. The dynamic structural design techniques of the aircraft industry could be applied with considerable advantage to machine tools, and, in view of the contracting state of the aircraft industry, this might be a profitable field for diversifying their activities.

3.2 Measuring systems

It is essential to be able to measure continuously the position of the slides of a controlled machine tool in order that control may be effected. The simplest method which can be adopted is to measure the movement of the slide in terms of the rotation of the leadscrew or a pinion in a rack-and-pinion drive. This is the method normally used in most hand-operated machines. It suffers from a number of drawbacks which limit its precision, namely that the screw must be accurate in pitch and that there must be no wind-up or lost motion larger than the required resolution. In practice, this limits the reliable resolution to about 0·005 in. on a small machine, and even this may require fairly frequent maintenance if it is to be held. However, for a number of purposes, this is adequate and it is possible to use a simple circular positioning device attached to the leadscrew or built in to the servo gearbox, with the advantage that it is simple to install and cheaper than a linear measuring system. In all other cases, however, ranging from small accurate machines to large machines where there may be transmission vagaries, a linear measuring system is required to measure directly the movement of the slide. The Ferranti diffraction grating measuring system* is now well known. The method of utilizing gratings for measurement is shown in Fig. 9. A suitable length of grating is attached to the machine table and a short length of grating attached to the other section of the slide so that one grating traverses the other with the two surfaces almost in contact. If a beam of parallel light is projected through the pair of gratings and they are suitably aligned, the moiré fringe pattern produced will modulate the light transmission when there is relative movement. One complete cycle of variation of intensity will occur for a movement equal to the pitch of the grating. By arranging four photocells in quadrature and by combining the outputs of the zero and 180°, and 90° and 270° cells in suitable amplifiers which reject the cophasal components, a two-phase electrical system can be formed, the amplitude of the vectors of which is substantially independent of the illumination and hence variations in transmission and ambient light changes. In this two-phase electrical system, the total number of cycles represents the distance moved, the frequency represents the velocity and the direction of phase rotation reveals the direction of movement of the slide. It is a simple matter to obtain from this system two or more discrete electrical pulses per grating line. Fig. 10 shows the finished optical assembly.

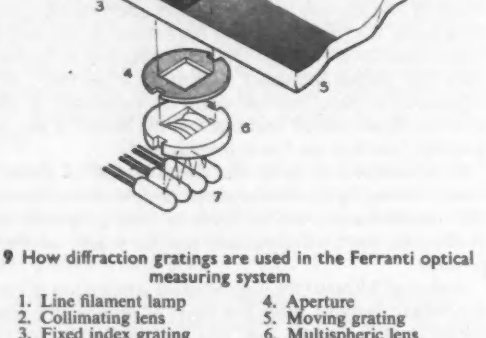


Fig. 9 How diffraction gratings are used in the Ferranti optical measuring system

1. Line filament lamp
2. Collimating lens
3. Fixed index grating
4. Aperture
5. Moving grating
6. Multispheric lens
7. Phototransistors

Fig. 10 Complete optical assembly suitable for fitting to a machine tool slide

This method has the advantage that the accuracy is unaffected by wear and can be made as high as desired. The index grating averages the line structure over its total area and, therefore, gratings can be joined simply be placing the ends together and phasing them. Resolutions from 0·005 in. down

* B.P. No 760'321 and subsequent applications.

to 1 micron are currently being used. Both variable density and prismatic gratings are used; prismatic gratings have decided advantages where the pitch is finer than 1000 lines/in.

The form of the measuring system will determine the number of transmission elements which are included in the closed loop of the servomechanism, and this has a profound effect on the overall performance of the system. The control of the angle of revolution of the transmission leadscrew, or the drive pinion in a rack-and-pinion transmission, relying on the accuracy and rigidity of these elements for the final accuracy of position, avoids many of the difficulties inherent with linear measuring systems when the whole transmission is included in the closed loop; but it is much less satisfactory because it is hard to maintain the initial accuracy and freedom from wind-up and backlash of the transmission elements during the hard life to which numerically controlled tools are subjected.

The alternative of including gearbox, transmission elements and slideway bearings in the feedback loop, although it requires considerably more knowledge for its design than open-loop systems, confers much greater benefits, because the initial accuracy, or the deterioration due to wear, of the components within the loop will have no appreciable effect on the overall accuracy of the system, and, therefore, very long life at high accuracy can confidently be predicted with a minimum of maintenance. In addition, induced vibration at low frequencies, owing to cutter impact on the workpiece, can be markedly reduced. The price in design effort which must be paid for this elegance is, in the early stages, high because each type of tool presents new problems. Ultimately, the behaviour

Fig. 11 The Fairey-Ferranti spar-milling machine is probably the first machine tool in the world specially designed for numerical control; its capacity is 24 ft × 7 ft

will be determined at the machine tool design stage when tools are specially designed for control. It is believed that the spar-milling machine shown in Fig. 11, which was designed for the Ministry of Supply as a fully integrated controlled machine tool, is the first machine tool in the world in which this has been done (*3, 4*).

3.3 Performance achieved with present techniques

The types of machine tool to which Ferranti control equipment has been applied include No 2, No 3 and No 4 size vertical milling machines, a 24 ft × 6 ft milling machine for cutting light alloy with a 20 b.h.p. high-speed head, a vertical column-type spar mill 25 ft × 7 ft with a 100 b.h.p. cutter head, a large experimental flame-cutting machine and a 30 in. × 20 in. jig borer controlled to exceptional accuracy for use as an inspection machine.

Feed rates up to 15 in./min with a resolution of 0·0002 in. have been provided on the No 2, No 3 and No 4 size milling machines, all of which have produced components to an accuracy of ± 0·001 in. and under good conditions can machine to an accuracy of 0·0005 in. All the milling machines are capable of carrying out the heaviest machining operations for which the spindles were designed because there is no lack of servo power. Under heavy roughing conditions, of course, some diminution of accuracy is to be expected because of deflexions in the cutter, the workpiece and the machine structure. Finishing cuts are required to produce high accuracy. The larger light-alloy machines have a resolution of 0·001 in. and an overall machining accuracy has been achieved well within 0·002 in. ± 0·001 in. per foot run.

The resolution of the flame-cutting machine is 0·005 in., and control accuracy is within 0·010 in.

4. ECONOMICS

4.1 Influence of data preparation cost

The costs incurred in using a system of computer-controlled production can be divided into two groups—data preparation and manufacture. The cost of converting a co-ordinate drawing of a component into the control tapes for the machine tool control unit is the greatest cost in the production of single components. In the Ferranti system, the cost of data preparation for a single component represents on average more than half of the total, but the total cost is on average about half the cost of manufacture by conventional methods. This is of great importance in applications such as toolmaking, template and prototype manufacture, where single components are made. The cost of using a control system which relies on hand calculation for data preparation is, in almost every case, higher than the cost of manufacture by conventional methods.

Increasing the number of components per tape steadily decreases the influence of the data preparation cost until it becomes no longer important for quantities greater than 10, and its place as the controlling factor in the economics is taken by the machining cost. The data preparation time can still be important in terms of delay in production, and it is found increasingly that the hidden savings which accrue from the use of numerical computer control methods, such as the smooth flow of work, and predictability of time schedules, ease of costing, saving in inspection time and storing, sorting and handling of patterns, jigs and fixtures, can be very worth while and would justify its use even when the straightforward production cost is comparable with conventional methods.

The curves of Fig. 12 are intended to give a qualitative idea of the variations in running costs which occur as the number of identical pieces is increased. The curves are derived with the cost of machining one component by conventional methods taken as unity. The curve for conventional milling falls on the usual 80 pc law, with a transition to copy milling shown after the third component. The copy milling curve roughly follows the curve of numerical control with hand calculation, as the template manufacturing costs and data calculation costs are of the same order, and although the copying machines may be lower in capital cost, they are the correspondingly slower because of servo problems, template changing, setting etc, which equalizes the curves for the large number of pieces.

Fig. 13 has been derived for the Ferranti system used in conjunction with a milling machine costing £6000 to enable judgment to be made of the probable economy for any projected component. It shows the total production cost per hour

of controlled machining plotted in terms of the ratio of planning time to controlled machining time, and of the number of components. The broken grid lines show for comparison the cost of conventional machining based on the

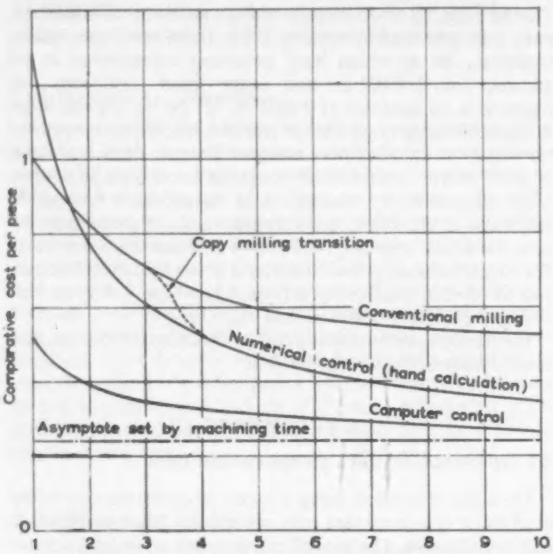


Fig. 12 Qualitative relations between the cost per piece and the number of pieces for various methods of manufacture

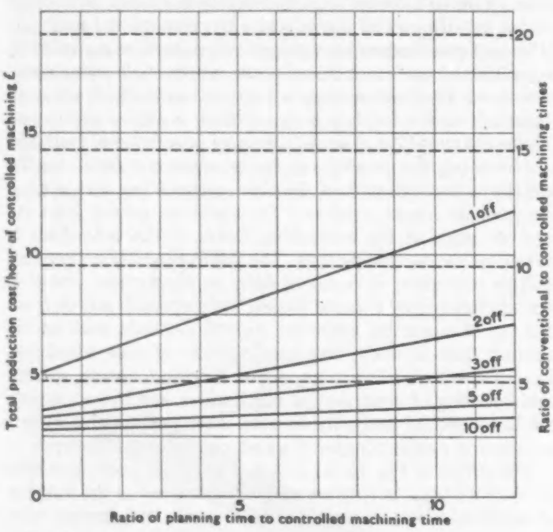


Fig. 13 A graph which enables a manufacturer to assess the relative costs of machining any component conventionally and on a numerically controlled £6000 milling machine

same data, expressed for convenience in terms of the ratio of conventional to controlled machining times on a basis of one hour of *controlled* machining.

For example, if on a particular component it is found that the ratio of planning time to controlled machining time is 5, the ratio of conventional to controlled machining times is 10, and the actual controlled machining time is 30 min, then the overall production cost/hour by computer-controlled methods, from the graph, would be just under £8 for a single component. This would fall, for three components, to just over £4. Looking at the right-hand side of the graph, the grid line corresponding to a conventional to controlled machining ratio of 10 indicates that the cost of the equivalent amount of conventional machining (i.e. 10 hours on a 'cost/hour of controlled machining' basis) is about £9 10s., so that, in this case, both 'one off' and 'three off' are cheaper by controlled methods. The actual costs are found by multiplying the cost/hour of controlled machining by the total number of equivalent hours of controlled machining; in this case £4 for one component computer-controlled, £4 10s. for one component by conventional methods and £2 each for three components computer-controlled. The 'three off' cost for conventional methods would have to be estimated from experience, and would vary in different organizations, but on the basis of Fig. 12 would be about $0{\cdot}7 \times$ £4 10s. or £3 3s. each.

4.2 Influence of the increase in production rate

Because the 'thinking time' has been moved to an earlier stage and streamlined, a numerically controlled machine spends all its working time cutting at top speed, and future developments will be directed towards steadily increasing the rate of metal removal for all types of machine. Since the numerically-controlled machine is inherently more expensive than the smaller hand-controlled machine, a significant reduction in the machining time for a given component is required to balance the data preparation cost. The machining time for a light-alloy component made on a computer-controlled machine can be as low as 2 pc, is never likely to be higher than 5 pc, of the time for a hand-controlled machine and might be between 30 pc and 50 pc of the production time on a copying machine. For steel components the corresponding times are 10–20 pc and 50–80 pc with present machining speeds. As cutter materials improve, the times for steel can be expected to approach those for light alloy.

It is clear that these figures allow the considerable increase in the hourly running cost of the machine tool to be borne with equanimity. The overall production time, including data preparation, for single components can vary from 20 to 40 pc of the conventional time, each additional component from the same tape reducing the overall time per component until this approaches the machining time asymptotically.

The increase in hourly running costs of the machine fitted with numerical control is dependent mainly on the ratio of the capital costs of the machine tool and the control equipment. For a large machine tool the increase is not very significant but with a smaller machine tool costing perhaps £6000, the hourly cost, including operator, might be increased by a factor between two and three.

4.3 Calculation of economics

An outline of the method of calculating the economics of computer-controlled machine tools has already been given (5) and can be used for evaluation of numerical control systems. Users and potential users could further the development of numerical control, as well as benefiting themselves, by carrying out cost investigations on their own types of work, treating with scepticism the statements of manufacturers regarding data preparation costs and machining costs. In general the only reason for using numerically-controlled methods is that they should be cheaper and better than other methods of manufacture, and no reputable controls manufacturer would wish to sell equipment on any other basis.

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Synchros are becoming smaller
— yet more accurate

Modern Trends in Synchros

An article which surveys current developments in synchro devices and points to new applications for these versatile control elements

by **J. BELL, M.Sc.,**
Chief Research Engineer, Muirhead & Co Ltd

THE WORD SYNCHRO, which is a generic term, is here widely interpreted as covering the class of machine or device used for the transmission of data for remote position indication or control. Usually the machines receive angular (rotational) mechanical inputs and give an output which is, perhaps after the interposition of a servo, yielded in the same rotational form. Various special types, however, are linear in character; also whilst most synchros are operated on an a.c.

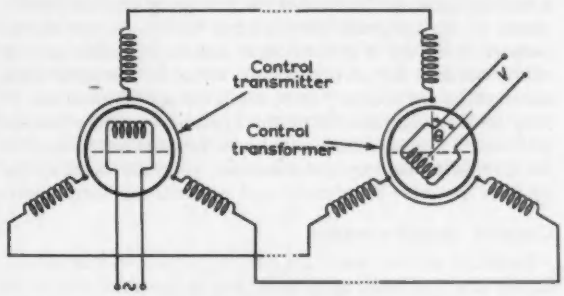


Fig. 1 The rotor of a synchro control transformer is not polarized by an external supply. It gives an output voltage V which varies with the angle θ and is zero when $\theta = 90°$. A control transformer is often used to feed an error signal to the amplifier of a servo mechanism

supply of frequency up to 1000 c/s, some use a much higher frequency. Moreover certain synchros operate on d.c. and others are optical in character.

Background

In common with many other devices the synchro owes its inception and development to the requirements of the Armed Services. Step-by-step motors preceded the synchro, but perhaps the earliest true synchros were those used in the German Navy for gunnery control in the First World War. These were crude machines, the inaccuracies being about $\pm 5°$, but later parallel developments in Great Britain, the USA, Germany and France produced various types of machine having a better performance, with inaccuracies of the order of $\pm 1°$ for direct indication and $\pm \frac{1}{4}°$ when

applied in a servo. In particular the developments best known in Great Britain were the Selsyn from the American General Electric Company, which was produced by BTH in this country and the Magslip from the Admiralty Research Laboratory, although many proprietary types, particularly for aircraft use, were also developed.

A typical proprietary instrument was the Desyn, which operates from a toroidal resistance ring having three 'phase' tappings to which the distant receiver stator is connected. Diametrically placed brushes energize the toroidal ring with d.c., and as they are rotated the permanent magnet rotor of the receiver follows. The errors are large ($\pm 2°$), but this is adequate for many indication purposes.

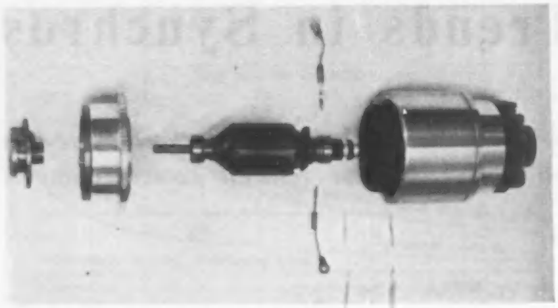


Fig. 2 An exploded view of a Magslip control transformer

After the Second World War many more types were evolved to meet special Service or civil uses, and these have been steadily improved in accuracy; the number of types and sizes now being manufactured is thus considerable. A unifying influence for synchros used in the Armed Services is fortunately operative, since NATO has decided to use only synchros in accordance with the US military specifications; these define the external dimensions for mounting and the performance of the synchros, leaving some latitude to the manufacturer in details of construction. Similar synchros may of course be used for civil purposes, either to the same tight specification for accuracy or to a relaxed specification according to the requirements of the application. Many manufacturers, however, produce synchros for civil purposes with no relation to military specifications, generally meeting the needs of a market for cheaper and less accurate instruments.

Output requirements

Synchros do not serve an end or purpose in themselves. Rather are they links in a chain, and hence their nature or design is subject to change in order to satisfy better the needs of the link as regards input and output of the synchro, and its size, power and accuracy.

One purpose of the early synchro was remote indication, the operation of a pointer visible to a human operator. This function still remains, and no change of design is required to meet present needs, but since smaller synchros are available they may when appropriate be used for this purpose.

The significant developments which have taken place are in the use of synchros in servo systems. Early servos employed an amplifying mechanism, or a contact-making device, or a hydraulic valve, etc. This required that the synchro rotor had to develop torque—first to move itself and secondly to do some external work, with the result that the synchro was usually large.

The more general adoption of electronic servo amplifiers, however, implies that the energy output from the synchro can be very small. Moreover the output element is of the control transformer type (Fig. 1) and the movement of the rotor is effected by energy derived from the servo motor; the necessity for making synchros large to produce adequate torque has disappeared, and the designing of miniature elements for computing and guided missile servos has become possible.

Accuracy and new production

Production synchros used in the Second World War had inaccuracies of the order of $\pm \frac{1}{4}°$. Post-war development, however, called for smaller inaccuracies as low as $\pm 7'$, more or less independent of the synchro size. New designs were evolved as experience was gained in the methods required to provide the higher accuracy. It is fair to say that the greatest efforts in improving accuracy were made in the USA, where the old large types of synchros were regarded as obsolete and a new range was introduced, whose code number is the external diameter in tenths of an inch.

The synchro elements (all 2-pole designs) now in production range from size 31 to 08; the largest serves as a transmitter energizing many controls in parallel with or without differential transmitters. As development has proceeded, however, and the methods of production have been refined, the smaller sizes have been used more and more; for example a size 15 transmitter may be used to energize a number of size 11 or 08 control transformers. The range of sizes and types is large; most are available for operation on both 60 c/s and 400 c/s, which are the standard frequencies adopted for military control purposes.

In the commercial, as distinct from the military, field various types of synchros have been evolved, some very similar to the US military types and others very similar to Magslips. The latter continue to be made in decreasing numbers for the Armed Services but in increasing numbers for commercial use in applications where their larger size compared with the standard military synchro is no disadvantage. Fig. 2 shows the principal parts of a Magslip control transformer. Magslip control with hydraulic amplification can be applied to many industrial operations; its application to weighing lime is sketched in Fig. 3.

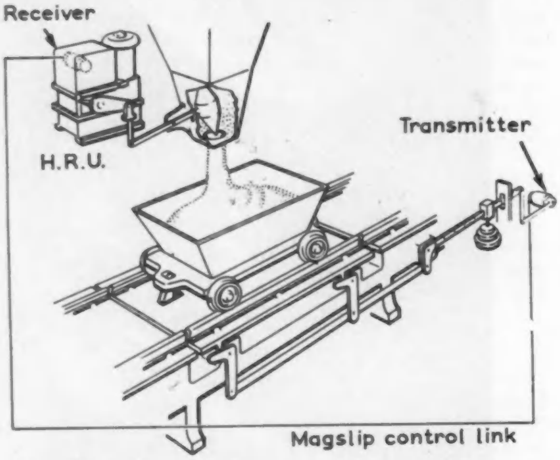


Fig. 3 Magslip control can be used for automatic regulation of industrial weighing
H.R.U.=Hydraulic relay unit

Production methods

How is the greater accuracy obtained with the new smaller synchros? Mainly by greater mechanical accuracy of the parts, improved assembly methods and precision final machining. The numerous component parts of a synchro control transformer are shown in Fig. 4.

a. *Stampings*. Much greater care is now exercised in the

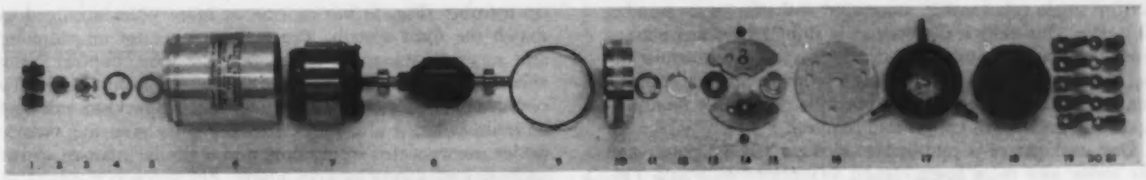


Fig. 4 A synchro control transformer contains a large number of component parts

1. Clamp assembly
2. Drive nut
3. Drive washer
4. Retainer ring
5. Shim
6. Housing
7. Stator
8. Rotor with ball-races fitted
9. Stator spring
10. Rear cap
11. Wave washer
12. 0·010 in. shim
13. Dust washer
14. Upper and lower retaining plates with screws
15. Packing washer
16. Insulating washer
17. Terminal ring assembly with screws and lock washers
18. Terminal ring cover
19. Terminal lugs
20. Lock washers
21. Terminal screws

production of stampings, so that they should be flat, free from burrs, concentric, accurately divided and made from high-quality material of uniform thickness. For example, in Magslip production during the Second World War, the individual stampings in general had mechanical errors exceeding the errors of the finished Magslip, reliance being placed on indiscriminate assembly of the stampings to form a pack having greater accuracy than the individual stampings.

Modern manufacture calls for stampings whose errors are of the order of $\pm$ 1′ to 2′. The error is reduced in the pack by providing a register mark showing how the stamping was produced from the tool and giving a reference to the grain of the sheet material. The table indicates the number of slots in the stampings of present-day synchros and Magslips.

SYNCHROS			MAGSLIPS		
SIZE	STATOR	ROTOR	SIZE	STATOR	ROTOR
31, 23, 18, 15, 11	15; 16 (resolver only)	12	3 in.	30	21
—	—	—	2 in.	24	18
08	12	9; 8 (resolver only)	1½ in.	18	12

NOTE: Most synchro transmitters and some Magslip transmitters have H-form rotors (single-phase energization).

b. *Assembly*. Assembly calls for progressive orientation of each adjacent stamping by one tooth, and thus errors due to stamping faults and magnetic quality variation with and across the direction of the grain are both averaged out.

Present practice is to bond the skewed pack of stampings by adhesion, and, after winding, to assemble the end covers and encapsulate the whole internally with an appropriate resin. With this type of construction goes the philosophy of non-repair of a synchro; if it fails, it is replaced.

c. *Machining*. With the assembly method just described the final machining of the stator bore and the ball-bearing seatings in the end covers is done at one setting—usually they are the same size and a through boring operation can be carried out, to give the best possible mechanical concentricity between bore and bearings.

d. *Ball bearings*. Extreme precision is required in the ball bearings used. They must have just the minimum clearance for free operation; they must be concentric, the inner with the outer, and be free from wobble or lack of rectangularity between the axis and the seating diameters. Ball bearings of adequate accuracy have been produced in Great Britain only recently and it is important that we should continue to keep technically abreast of other countries in the manufacture of these highly accurate components.

e. *Driving attachments*. Great care must be exercised in the production of the gear wheel or coupling to drive the synchro and in its attachment to the shaft, so that the accuracy which has been attained in the element is not lost in its application. This problem becomes more difficult as the size of the synchro decreases; with size 11, for example, a gear wheel of 0·9 in. diameter approximately is the largest that is desirable for use with a servo arrangement, so that it is capable of permanent fitting on the synchro, and thus smaller in diameter than the synchro seating register. A simple calculation shows that an error of $\pm$ 1′ is caused by an eccentricity of 0·00013 in. in a gear wheel of 0·9 in. diameter. Modern production machine tools alone have made consistent production of this quality possible. This same order of precision is required in the machining of the synchro itself as is implied in (c) above.

Multi-polar synchros

In addition to the normal two-pole construction of synchros, variations exist and new types are being evolved to meet various needs and in particular to obtain greater accuracy. The proportions of a two-pole design usually are such that the bore diameter and core length are comparable; but gyroscope pick-off units, for example, have for some time used a design of short axial length, yet still having two poles. A modern variation of this is the multi-polar design with as

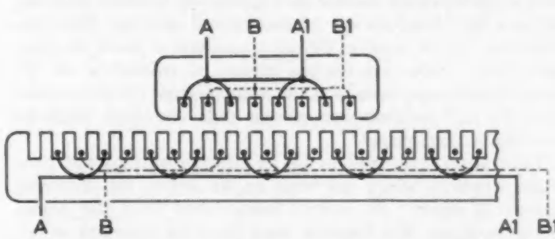


Fig. 5 How the poles are arranged in a linear synchro

many as 18 poles, which relies on the averaging effect of a large number (and of course also on the orientation of stampings) to obtain improved accuracy. Because of the small number of teeth per pole, which would tend to produce an inferior output waveform, an important feature of the multi-polar design is that the stator (or rotor) has an extra tooth; thus the pole pitch is somewhat less than the 360° divided by the number of poles, and the relation between rotor and stator is that of a vernier. The output of the large number of poles with series connexion is thus improved, both in accuracy and waveform. Total errors of the order of 2′ can be obtained—referred to the 360° mechanical angle of the instrument—and the electrical output has the steeper voltage

solidus angle relationship associated with the larger number of poles. This electrical response is similar to that obtained from the 'fine' element of a geared 'coarse-fine' transmission, but the troubles and inaccuracy of the mechanical gearing are avoided. A coarse element or other means of unambiguous alignment is of course still required.

One example of a multi-polar element has 12 poles, and the stator and rotor have 72 and 49 slots respectively. This can be conveniently wound three-phase or two-phase on the stator, and two-phase or single-phase on the rotor, one slot being left unwound to give the desired vernier effect.

Another development has been described by Kronacher.* It is called by the author of the article a *vernier resolver*. This is almost a contradiction in terms if a resolver is thought of as

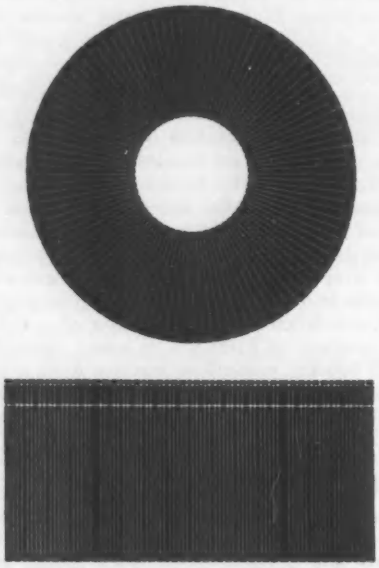


Fig. 6 Metallic patterns on glass disks or strips are used as active elements in rotary and linear Inductosyns

giving sine and cosine functions in terms of shaft angle. In effect the resolver represents a precision angle transducer, with a performance similar to a geared-up synchro resolver, without the disadvantage of mechanical gearing. The construction, which involves different numbers of teeth on rotor and stator, relies on the variations of reluctance of the multiple magnetic circuits as the inductor-type rotor is turned from the null position through less than one tooth pitch, to give the vernier output.

The transmitting resolver has an exciting winding and two-phase windings which are both on its stator; the receiving element is similar, the output being taken from the single-phase winding. The element may thus be regarded as an elaboration of the magnetic pick-up used for operating, for example, from a gyroscope for position control. Accuracy of the order of $\pm$ 5 sec is claimed. The vernier resolver has potential applications in angle encoders, servo position systems, etc where high accuracy is required. It is normally used in conjunction with a standard synchro element acting as a coarse angle transducer.

Linear synchros

Linear position control—such as the control of the saddle or work table of a machine tool—has given rise to various devices, among which is the linear synchro. It consists of a continuous system of wound magnetic teeth constituting a large number of poles; over these is arranged to slide a pick-up member (Fig. 5) having one or more poles arranged to match the fixed system. The pick-up operates an amplifier and servo arrangement completing the loop, control being effected from a synchro transmitter of the normal type. To obtain sufficient accuracy the linear synchro pick-up unit may be multi-polar, it also may be arranged to have the vernier device incorporated in the design in a similar manner to the multi-polar system described above. The synchro is wound as a two-phase element but three-phase windings could be used instead.

* *Bell Syst. tech. J.* 1957, 36, p 1487

The Inductosyn

This is a special kind of synchro produced in the USA. It operates on, for synchros, a very high frequency of the order of 10 kc/s, and uses no iron in its construction. Linear and rotary types are available.

The windings have two phases and are deposited on glass plates. In the rotating type, the plates are annular and are mounted close to each other, one being rotatable and the other being the stator. Fig. 6 shows the character of the elements for the linear and circular instruments. The former consists of a glass 'scale' and 'slider', analogous to a rotor and stator respectively (only the scale is shown in Fig. 6). The slider has two windings 90° out of phase with each other. The pole-pitch is 0·10 in. and subdivision of this depends upon the accuracy of the two-phase resolution. A multi-polar unit is used both in the rotary-type transmitter and the linear receiver, and a positional accuracy of the order of 0·0001 in. is claimed.

Two rotary elements can of course be used as transmitter and receiver to constitute a normal control link. There would appear to be no essential reason why a differential transmitter could not be made, but its use would most probably involve the interposition of precision linear amplifiers between the Inductosyns, because the efficiency of the Inductosyn cannot be high.

The main application of the linear Inductosyn is to machine tool control, the slider being mounted directly on the moving carriage. The rotary type can be used as a high-accuracy synchro, with a standard synchro as a coarse data transmitter or receiver. Coupled to a resolver, it can form an electronic gear; if an Inductosyn of 108 poles is used with a two-pole resolver a ratio of 54 : 1 is achieved—step up or down depending on which element is used as the input.

Other special types of transmission or receiving units can be made using a technique akin to optical interferometry with 'gratings' generally of coarser pitch; these operate giving a two-phase output, similar to a synchro resolver and may be linear or circular.

Smaller synchros cannot be wound for the normal voltages (115 V for rotor excitation, 90 V for stator excitation, and 60 V for control transformer output). For such synchros 26 V is being accepted fairly generally and as it turns out this matches the requirements of transistor amplifiers.

Conclusion

The synchro requirements for the future seem to be very wide. Only the old large US Navy synchros have really gone out of production; the others all have their special fields of usefulness, but for military needs in particular, the emphasis will continue to be on smaller sizes of control elements and motors—the 05 size is already being planned and the 03 size is being talked about.

For civil purposes Magslips and the larger synchros will continue to be used in addition to the small sizes, whichever suits best a given application. For simple indication and perhaps also for remote operation of small mechanisms, the resistance transmitter (or commutator) with a d.c. or permanent magnet receiver will continue to fulfil a useful function.

Electronic process control systems are new—but their potential applications are wide

ELECTRONIC SYSTEMS FOR INDUSTRIAL MEASUREMENT AND CONTROL—2

by **M. V. NEEDHAM**, *Assistant General Manager (Industrial), Elliott Brothers (London) Ltd*

The first part of this article appeared in CONTROL *last month; it discussed some general principles of electronic plant control and began the description of a particular a.c. system, which is continued here.*

4.5 Additional examples of computation

Section 4.4 in Part 1 of the article explained how summation, multiplication and division can be carried out by a.c. analogue circuits, using resistors, amplifiers and differential transformers. Here methods of carrying out three other mathematical operations are outlined.

Finding square roots. This can be performed by using an indicator or recorder in which two differential transformers are driven together by the same torque motor, as is shown in Fig. 13a. By energizing the second transformer by means of an amplifier with a gain of 230, fed from the first differential transformer, an output proportional to square of the torque motor rotation θ is produced. The servo action equates this to the input signal so that

$$x_1E = E\theta^2$$

and

$$\theta = \sqrt{x_1}$$

Thus the first transformer output is $E\theta = E\sqrt{x_1}$ and this signal is suitable for transmissions to other recorders and indicators or to a controller.

Squaring. Fig. 13b shows how the same basic arrangement can be used for squaring.

Integration. The amplifier, energizing the second differential transformer in the square-root device, in Fig. 13a, provides a linear flow signal if the input quantity x_1 is a measure of, say, a venturi differential pressure. This can be used to drive an integrating milliampere-hour meter in addition to the second differential transformer and so give an indication of total flow.

5. Control with an a.c. system

It is generally true that it is difficult to make an accurate prediction of the dynamic behaviour of industrial processes. Although the type of control to be used can be decided in advance, it is usually necessary to determine the values of proportional band, etc, during plant commissioning. Accordingly the controller, shown in the simple control loop of Fig. 1 (July, p 4), must provide for the easy adjustment of the coefficients K_1, K_2 and K_3, so that acceptable control quality can be achieved.

Since the controller is a vital part of the control loop, it is essential that a fault can be located easily and that remedial action can be taken quickly. To this end, the controller for use with the a.c. system of measurement, described in Part 1 of the article, is in the form of plug-in units which can be readily replaced should a fault develop. Repair can then be carried out with no further plant disturbance.

As will be shown, the controller can be used in extensions of the simple loop such as cascade control and ratio control. Its output signal is equally suitable for use with electropneumatic and electrohydraulic valve operators.

5.1 The controller

This unit, which can be fitted on the mounting case of the recorder of Fig. 10 (July, p 8) to provide a complete recorder-

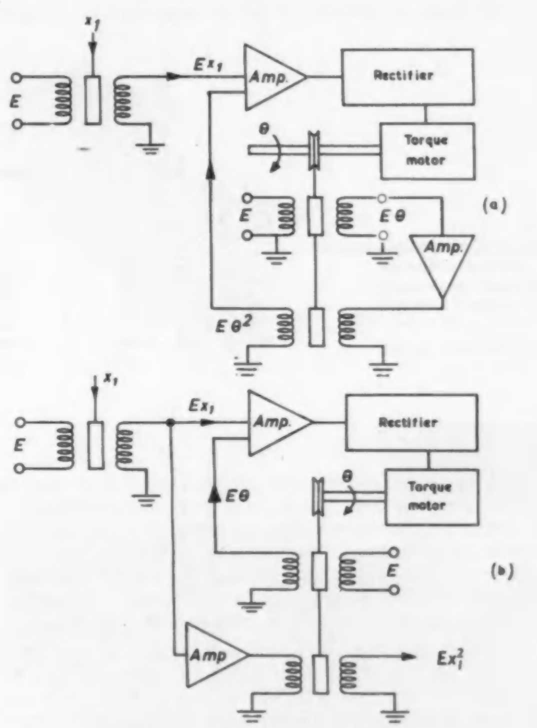


Fig. 13 Finding square roots and squares

(a) Square root
At balance $E\theta^2 = Ex_1$
Therefore $\theta = \sqrt{x_1}$

(b) Squaring
At balance $Ex_1 = E\theta$
Therefore $\theta = x_1$
Thus output $= Ex_1^2$

controller unit, accepts 0–0·5 V a.c. signals representing the measured and set-point values. The set-point signal is fed from a manually adjusted differential transformer, of the type used in the measuring instruments, so that the correct phase is assured. Although normally mounted in the recorder or indicator unit, it can be mounted separately on the instrument panel. When mounted in the recorder or indicator a pointer is provided for comparison with the measured value. The controller output is a direct current in the range 1–5 mA and can be direct or reverse acting.

The following modes of control can be provided:

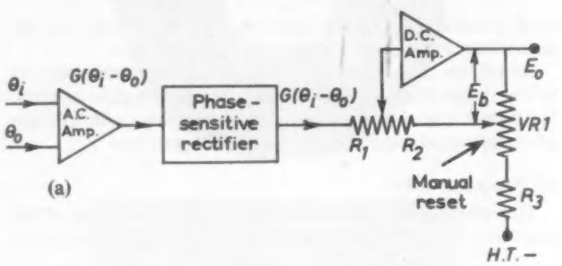
a. Proportional with manual reset

b. Proportional with rate action and manual reset

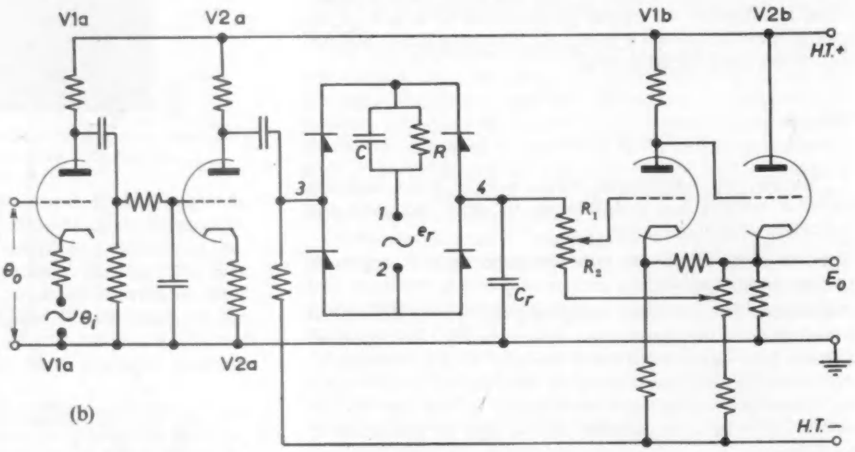
c. Proportional with automatic reset

d. Proportional with rate action and automatic reset.

a. *Proportional control.* The block diagram of the proportional controller is shown in Fig. 14a. Set-point and measured variable signals, θ_o and θ_i, are fed to a fixed-gain a.c. amplifier giving an output $G(\theta_i - \theta_o)$. This signal undergoes a 180° phase reversal with change of sign of the error signal $(\theta_i - \theta_o)$,



(a)



(b)

Fig. 14 Proportional control with manual reset

(a) Basic arrangement

$E_o = G\frac{R_2}{R_1}(\theta_i - \theta_o) + Eb$

(b) Simplified circuit

and the phase-sensitive-rectifier output is positive or negative according to this sign. The rectifier error signal is amplified by a variable-gain output stage consisting of a high-gain d.c. amplifier with feedback. The gain with feedback is R_2/R_1 (Fig. 14) and can be adjusted by altering the ratio. An adjustable bias voltage E_b, from the potential divider *VR1* and R_3, provides a manual reset voltage in series with the output.

Essentially simple circuits are used, as can be seen from Fig. 14b. The error signal is formed by feeding θ_i and θ_o to the grid and cathode of V1a, and the coupling between V1a and V2a adjusts the phase of the amplified error signal to that of the phase-sensitive-rectifier reference voltage. The phase-sensitive-rectifier is of the diode switch type. During alternate cycles of the reference voltage terminal 1 is negative with respect to terminal 2 and current flows in all the diodes. When this occurs a low-resistance connexion is formed between 3 and 4. Since a bias voltage is built up on capacitor *C*, the diodes conduct, for a short time only, at the peak value of the reference voltage. As the error signal is in phase with the reference signal, its peak value is transferred by the switch into the reservoir capacitor C_r, which smooths out the pulsations at line frequency, so that a substantially steady voltage proportional to the error is fed to the feedback output amplifier. Reversal of the connexions of the reference voltage changes the sign of the rectified error signal, enabling direct or reverse action to be simply achieved.

b. *Rate action.* When rate action is required the circuit of Fig. 15 is inserted between the phase-sensitive rectifier and the output d.c. amplifier. This rate circuit consists of a high-gain d.c. amplifier with feedback. In the absence of C_d the gain is given by $(S_2 + S_3)/S_1$, which is unity if $S_2 + S_3 = S_1$. However, with C_d present, feedback is reduced with increasing frequency and an additional term, proportional to the rate of change of the input, is introduced. The relation between output and input is then given by

$$E'_o = \frac{S_2 + S_3}{S_1}\left[1 + \frac{S_2 S_3}{S_2 + S_3} C_d p\right] E_i$$

and with $S_1 = S_2 + S_3$ the controller output becomes

$$E'_o = G\frac{R_2}{R_1}\left[1 + \frac{S_2 S_3}{S_1} C_d\, p\right](\theta_i - \theta_o)$$

giving a rate action time

$$T_d = \frac{S_2 S_3}{S_1} C_d$$

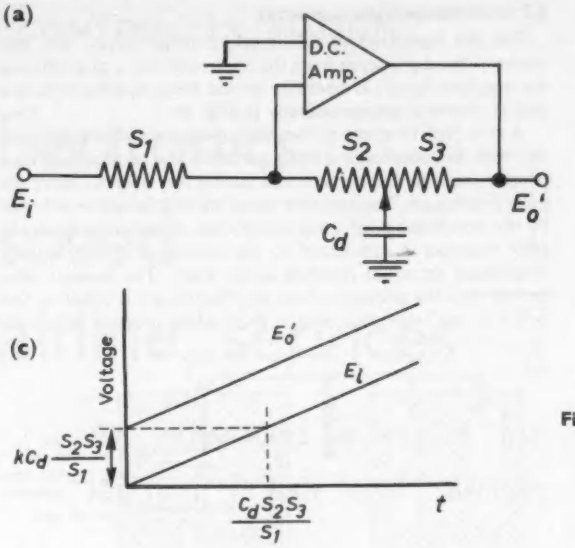
The action of this circuit in response to a steady rate of change of input voltage is shown in Fig. 15c.

Since T_d is adjusted by altering the tapping on $S_2 + S_3$, the proportional band is unaffected, and non-interacting adjustment, of rate action and proportional band, is achieved.

c. *Automatic reset.* The basic arrangement used for the generation of an integral term is given in Fig. 16a. It consists of a high-gain d.c. amplifier with feedback via a series resistor and capacitor. In response to a step function input, since the capacitor behaves instantaneously as a short-circuit, the gain is given by R_2/R_1 (Fig. 16). Following this the capacitor charges in a linear manner. For this arrangement the output voltage is given by

$$E'_o = \frac{R_2}{R_1}\left[1 + \frac{1}{C_i R_2}\cdot\frac{1}{p}\right] E_i$$

The integral action time is thus $C_i R_2$, the proportional band is R_2/R_1 and the reset rate, $1/C_i R_2$, is independent of R_1. Non-interacting adjustment, of proportional band and reset



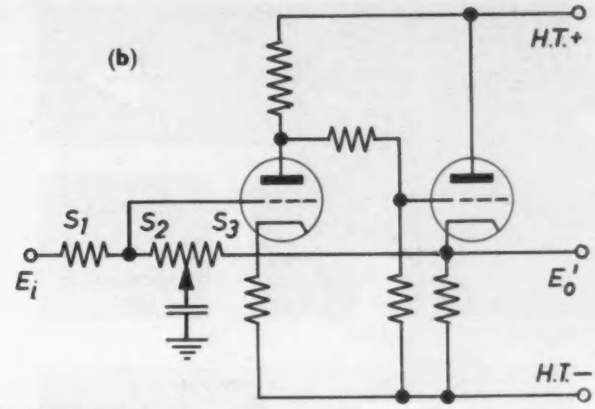


Fig. 15 Rate action unit

(a) Basic arrangement
(b) Simplified circuit
(c) Response to ramp function

$$E_i = kt$$

$$E_o' = kt + k\frac{S_2S_3}{S_1}C_d$$

rate, is thus possible since the former is adjusted by R_1 with no effect upon the reset rate. On the other hand adjustment of R_2, with a simultaneous proportional adjustment of R_1, results in a variation of reset rate with constant proportional band.

Fig. 16b shows the basic circuit used. The resistances R_1 and R_2 consist of a set of resistors, mounted on circular cards, with printed switch contacts. Both cards are rotated to adjust reset rate so that R_1 and R_2 vary in proportion. The sliding contact, of R_1 only, is moved relative to its card to adjust the proportional band.

The design of the controller is such that up to four of a number of printed-circuit packages can be plugged into a common mounting case, as shown in Fig. 17. These combinations provide for any one of the control modes mentioned, as shown in Fig. 18. The individual units are as follows:

Power unit. This is used in all combinations and is a simple transformer and metal rectifier unit providing heater and h.t.

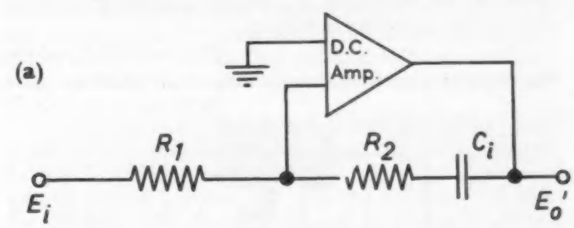
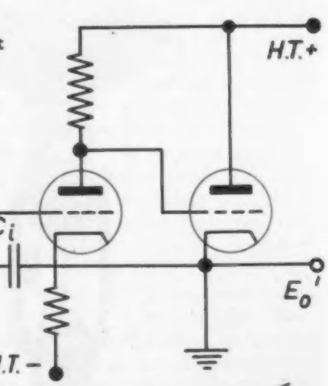
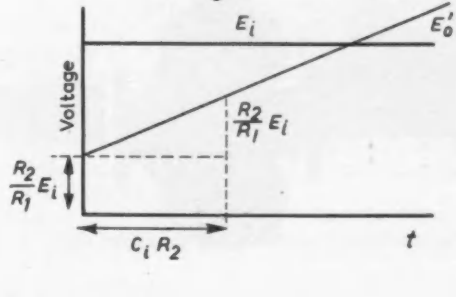


Fig. 16 Automatic reset unit

(a) Basic arrangement
(b) Simplified circuit
(c) Response to step input
Input = $E_i 1$

$$E_o' = \frac{R_2}{R_1}\left(1 + \frac{1}{C_iR_2}T\right)E_i$$





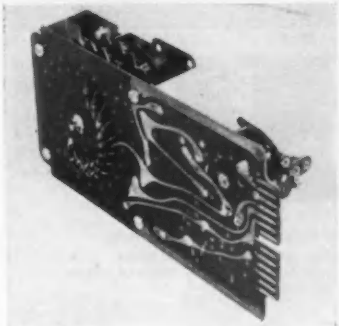
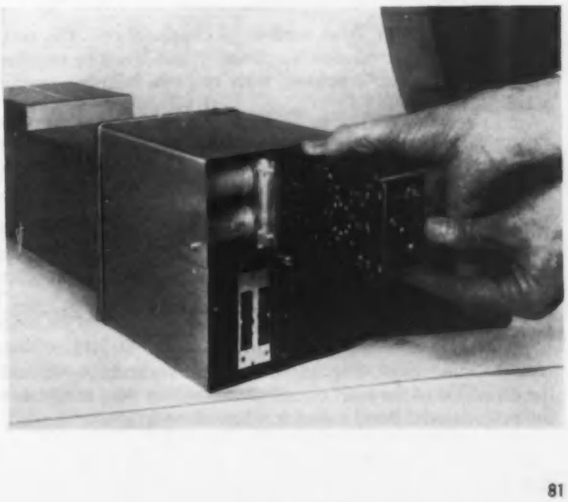


Fig. 17 The electronic controller has plug-in units for flexibility and easy maintenance



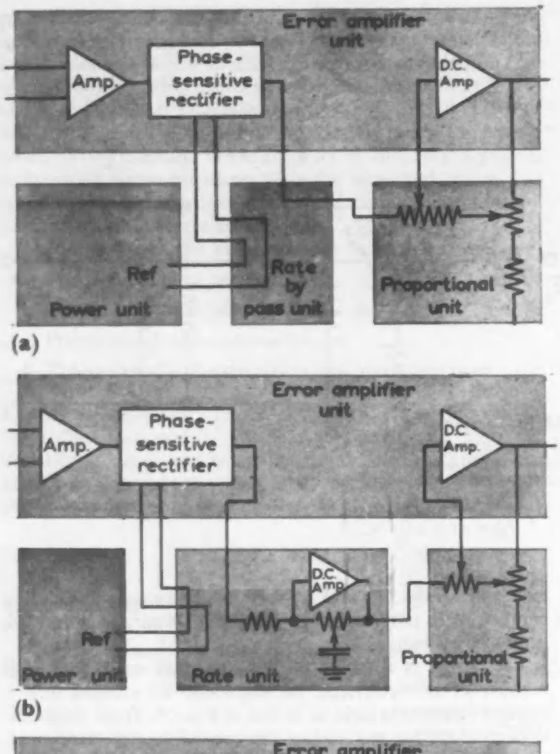


Fig. 18 Combinations of controller units
(a) Proportional and manual reset
(b) Proportional, rate and manual reset
(c) Three term

supplies. It also provides the reference supply to the phase-sensitive rectifier.

Error amplifier unit. Also used in all combinations, this consists of the a.c. fixed-gain amplifier, phase-sensitive rectifier and high-gain d.c. amplifier with cathode-follower output stage.

Proportional unit. This is used in combinations 1 and 2; it mounts the feedback resistors, R_1 and R_2, and manual reset potential divider shown in Fig. 14a.

Rate-bypass unit. When rate action is not wanted, this serves as a connector between the phase-sensitive detector and the proportional unit.

Rate action unit. This consists of a high-gain a.c. amplifier together with the rate action feedback network.

Automatic reset unit. This unit mounts the resistors R_1, R_2 and the capacitor of the reset circuit shown in Fig. 16a. It replaces the proportional band network when automatic reset is used.

5.2 Electropneumatic convertor

For the operation of pneumatic control valves, this unit converts the d.c. output from the controller into a proportional air pressure signal. It operates on the force-balance principle and is shown diagrammatically in Fig. 19.

A coil, free to move in the field of a permanent magnet, is fed with the controller output current. The resulting force is proportional to the current and causes the lever to move the pilot diaphragm. The pressure under the diaphragm is adjusted by the non-bleed pilot until equilibrium is restored. Since the pilot chamber is connected to the underside of the booster diaphragm an equal pressure exists there. The booster pilot moves until the pressure above the diaphragm is equal to that below it, and when this occurs, the loading pressure is directly

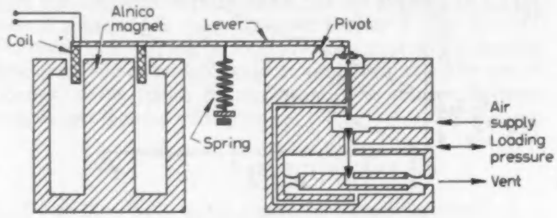


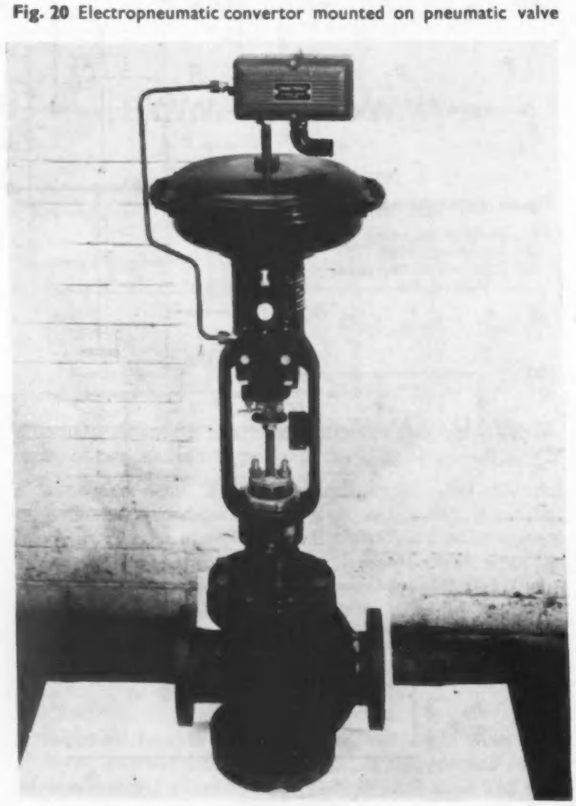
Fig. 19 Schematic of the power relay
The electrical d.c. input is fed into the coil on the left of the diagram

proportional to the input d.c. With normal adjustment, a loading pressure of 3–15 lb/in² corresponds to 1–5 mA d.c. input. Other output pressure ranges are possible by using booster diaphragms of different diameters.

The convertor is preferably mounted directly onto the valve operator, as shown in Fig. 20. In this way there is no lag due to air signal transmission, and since provision is made, in the convertor, for the fitting of a heating element no problem should arise in freezing conditions.

To be concluded in the next issue

Fig. 20 Electropneumatic convertor mounted on pneumatic valve



CONTROL IN ACTION

Electronics speed airline services

An advanced autopilot for leading British civil aircraft

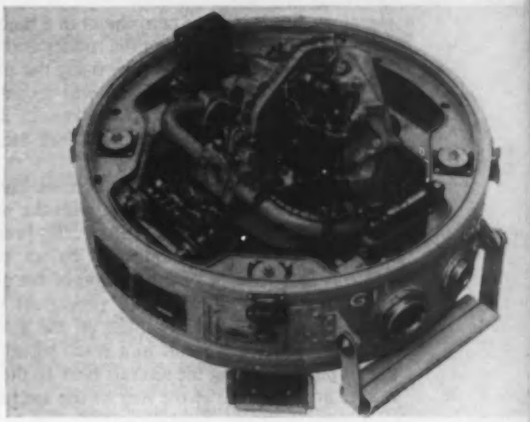


Fig. 1 The sensitive nerve centre of the autopilot. A plastic dome fitted over the unit leads to better handling by mechanics

READERS WILL REMEMBER in the last issue of CONTROL a short article on the flying controls of the Comet IV and in this issue we take the subject further by describing the autopilot mentioned in that article. The autopilot is the Smiths SEP2 which is under development and production by Smiths Aircraft Instruments Ltd, in a pleasant, contemporary factory near Cheltenham. The SEP2 is meant to be fitted as standard equipment by BEA to their new Viscount and Vanguard aircraft, and by BOAC on their Britannias and Comet IVs.

The autopilot has long been regarded as an essential piece of operational equipment on British civil aircraft. Today, it is even more essential for flying fast aircraft under arduous and tedious conditions. In fact both the economic operation and service reliability of a modern airline depend upon the efficiency of its aircrafts' autopilots.

The performance limits of a modern autopilot are set by an operator's requirements. It seems likely that the equipment for fully automatic landing could be made available if an operator wanted it, but at this stage the airlines do not feel that the extra cost is justifiable. The extra cost would be involved in fitting equipment to prevent manoeuvres at landing which would have been acceptable at higher altitudes. There is also the safety aspect. At high altitudes the autopilot may break down, but it is designed to fail in a safe manner, so that the aircraft will not suddenly plunge into a manoeuvre, though it may slowly veer off course or change height. However, at landing the pilot may not be quick or competent enough in taking over the controls after a failure, which might then lead to a disaster. These problems of safety and tighter control of the aircraft are not insurmountable, but it does mean that the equipment becomes more complex. This complexity, together with a possible weight penalty, signifies extra capital to an operator, who thus prefers a relatively simple and cheap autopilot with the landing carried out by a human pilot. The limitation of the human pilot lies in the fact that he cannot land in adverse conditions, such as fog, and so the aircraft must be diverted to an alternative aerodrome or return to its point of departure. It is this latter limitation which may decide the operators in favour of completely automatic landings. By doing this they will render flying independent of the weather, with a consequent increase in service reliability. Automatic landing will inevitably lead to a linking of the engine controls with the flying controls, and we may only conjecture at the many interesting problems that lie ahead in this fascinating branch of control engineering.

The SEP2 is an advanced autopilot which has been designed to follow complex navigational procedures in all weathers, and bring the aircraft on a fully automatic landing approach to within 200 ft of the ground. This 200 ft is the limit set by the Air Registration Board, who contend that if a pilot cannot see the ground at this height then it is time for him to go up again. The equipment mainly works on a 115 V, 400 c/s, three-phase supply taking 3 amp/phase at a power factor of 0·8.

Rate gyros and manual controls

The nerve centre of the autopilot is shown in Fig. 1. This consists of three gyroscopes mounted mutually at right angles on a platform, which is itself supported on gimbals. The gyroscopes used are rate gyros, which give a linear displacement of the output axis directly proportional to the rate of turn about the input axis. The linear displacement is changed to a signal voltage by a variable transformer pick-off, one arm of which is fixed to the gyro. Though they are not shown on Fig. 2 there are two motors which can alter the plane of the platform. The bank platform motor drives shaft A and the pitch platform motor drives shaft B. The gyro platform can be regarded as normally level and fixed to the aircraft. Thus if the aircraft deviates in roll, pitch or yaw from the plane set by the gyro platform, a signal is sent from the respective pick-off to a servomotor which will correct that deviation. Fig. 3 shows a simplified block diagram of the three servo control channels.

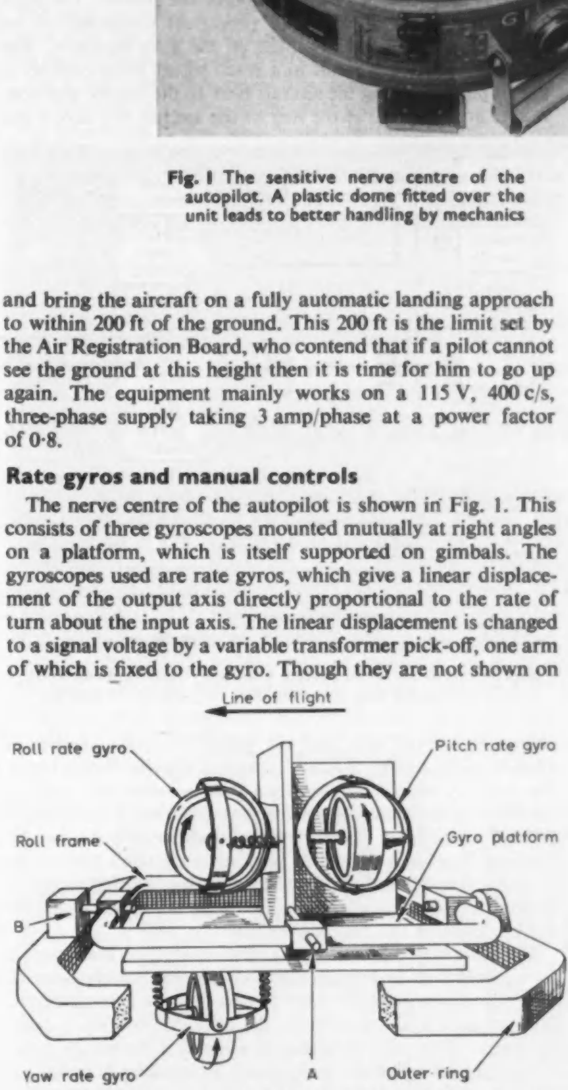


Fig. 2 The three rate gyros are mounted on a platform free to swing in gimbals

The pitch altitude of an aircraft is controlled only by the

elevators, but it is more convenient in a high-speed aircraft to change the heading by using the rudder and ailerons together, and not as one might expect, by using the rudder alone. Thus any deviation in heading (yaw) will result in the yaw gyro signal being applied to both the rudder and aileron servo channels; this leads to more efficient stabilization of the aircraft and is known as *cross-feed.*

A very low rate of disturbance, or change of attitude, cannot be detected by the gyros, with the result that the aircraft could slowly alter its attitude. To prevent this, each of the servo channels is monitored by an external reference which is independent of the motion of the aircraft. The pitch monitor consists of a simple pendulum connected to an inductive pick-off and mounted on the gyro platform. Any change in pitch will result in a small signal being applied to the amplifier to bring the aircraft back to the desired position. A similar pendulum at the rear of the aircraft will detect any

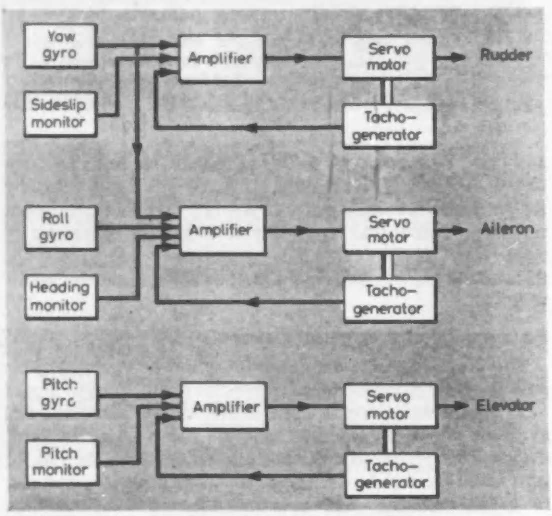


Fig. 3 The three servo control channels. There is much more in the autopilot than this simplified diagram would suggest

change in the roll axis, and the signal from this monitor is applied to the rudder channel to prevent sideslip during turns. The heading selector is basically a remote indicating compass operated by the main compass system and contains a monitor pick-off which is set to enable the aircraft to follow a desired heading. Any drift from this heading is detected and, since the aircraft is steered by the ailerons, a monitoring signal is applied to the aileron channel to bank the aircraft and so bring it back to the desired heading.

The pilot may manoeuvre the aircraft without disengaging the autopilot. If he presses the pitch control switch forward the pitch platform motor starts to run, and the gyro platform is tilted backwards relative to the aircraft. The pitch gyro treats this tilting as a disturbance which has moved the nose of the aircraft upwards. It responds by sending a signal to the elevators which will bring the nose down, and in this way the aircraft will start to descend to a lower altitude. If the pitch control switch is pulled backwards the pitch platform motor tilts the platform forward, and the gyro sends a signal to the elevators which will make the aircraft ascend. Once the platform has been tilted the aircraft will continue to ascend or descend until the platform is brought back to the level position. In a similar manner turns are made by using the turn control knob. A rotation of the knob will set the bank platform motor running and this will tilt the gyro platform sideways. The platform movement will be detected by the roll gyro which will send a signal through the aileron channel to bank the aircraft into a turn. When the control knob is returned to the central position the bank platform motor will run in the reverse direction until the aircraft is flying straight and level again.

As well as being operated by the manual controls, the platform motors can be operated by signals from other control systems. In this way the aircraft can be maintained at a constant height or altitude, set at a predetermined bearing or made to respond to the signals from an instrument landing or navigation signal. Only one system at a time can be coupled to the autopilot.

Automatic position controls

The height detector consists of an evacuated capsule coupled to an electromagnetic pick-off so that changes in air pressure, and hence height, will produce proportional output signals from the pick-off. When the height lock is not engaged, the datum of the height detector is continually reset to zero. As the aircraft changes height, the signal from the pick-off is amplified and used to drive a motor in such a sense as to reduce the pick-off signal to zero. When the height lock is engaged the resetting motor is disconnected, and the signals from the height detector are applied to the pitch platform motor, which will make the aircraft climb or dive as is required to keep the desired height.

Since the level-flight attitude of an aircraft varies with speed it is impossible to set the attitude control (pitch datum potentiometer) at any one setting, and the potentiometer must remain capable of being reset to correspond with any airspeed. Accordingly, the pitch datum potentiometer is driven by a pitch error integrating system which, by ensuring that any height error is ultimately reduced to zero, enables the height lock to be engaged during climbing or during flight, and ensures that the aircraft automatically takes up the level-flight altitude appropriate to its speed. A block diagram is shown in Fig. 4.

The airspeed lock works in the same manner as the height lock, except that the evacuated capsule is replaced by one sensitive to airspeed. The signals from the airspeed detector are applied to the pitch platform motor, which will drive the gyro platform, and so the altitude of the aircraft, in such a direction as will restore the airspeed to that at the time of engaging lock.

In the vertical plane the correct line of approach, or glide path, down to an ILS (instrument landing system) equipped runway is marked by the beam from a glide path radio transmitter. The correct glide path, as indicated by the centre-line of this radio beam, is normally inclined at an angle of about 2 deg from the horizontal, and transmitted signals can be received and interpreted to inform the pilot of a suitably equipped aircraft whether the aircraft is flying on the correct glide path or not.

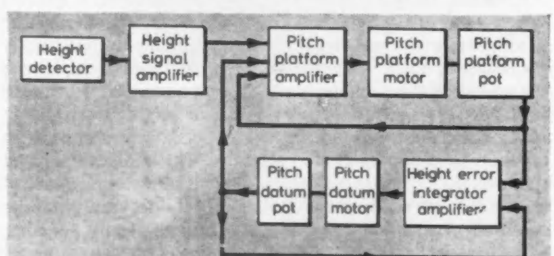


Fig. 4 The aircraft is kept at a predetermined height by the height-lock control circuit

In the glide phase of automatic approach, the signals from the ILS glide path receiver in the aircraft are amplified and applied to the pitch platform motor to control the aircraft's descent to the runway. Apart from the different origin of the control signals, the pitch platform control circuit is much the

same as for height lock control, one difference being that the pitch datum of the aircraft is changed by 2 deg nose-down from level flight when glide path control is engaged.

The heading selector is basically a compass repeater indicator operating from the aircraft's master compass. The master compass transmitter sends three-phase signals to the stator windings of a synchro control transformer. The signal from the rotor output is used to drive the rotor so that its output is reduced to zero. A compass card is attached to the rotor and in this way it repeats the magnetic heading. A pointer on the heading selector can be set to a desired heading, and the signal from a potentiometer wiper is then proportional to the heading error (i.e. the difference between the selected heading and the magnetic heading). When a pushbutton is pressed the heading error is applied to the bank platform motor, so that the aircraft will turn automatically on to the desired heading.

In the horizontal plane the line of approach, or track, to an ILS equipped runway is marked by a localizer beacon which transmits a radio beam 5° wide, and has a range of about 30 miles at a height of 2000 ft. A pilot with suitable ILS receivers can thus tell whether he is on the correct track or not. If the receivers are coupled to the autopilot and if the heading of the aircraft on landing is set on the heading selector, a completely automatic landing approach can be made. The heading error signal is mixed with the ILS deviation signal and the result fed to the bank platform motor. The aircraft will now approach the radio beam gradually and with minimum overshoot, and will then fly along the correct line of approach to the runway.

In navigating an aircraft it is often necessary to fly along a VOR radial which is a radio beam given out by a ground station (VOR = very high frequency omnidirectional radio). The pilot can select a VOR frequency to be fed into the autopilot and the aircraft will then fly along it, using a circuit similar to those described for the ILS localizer beacons.

In a few short paragraphs it is impossible to do justice to the refinements of this sophisticated autopilot. No mention has been made of the close integration of the autopilot with the instrumentation provided for the pilot, which has itself been intensively developed. However, perhaps enough has been described to show the significance of the SEP2 as a step to the development of completely automatic aircraft control.

ICI mobile data logger

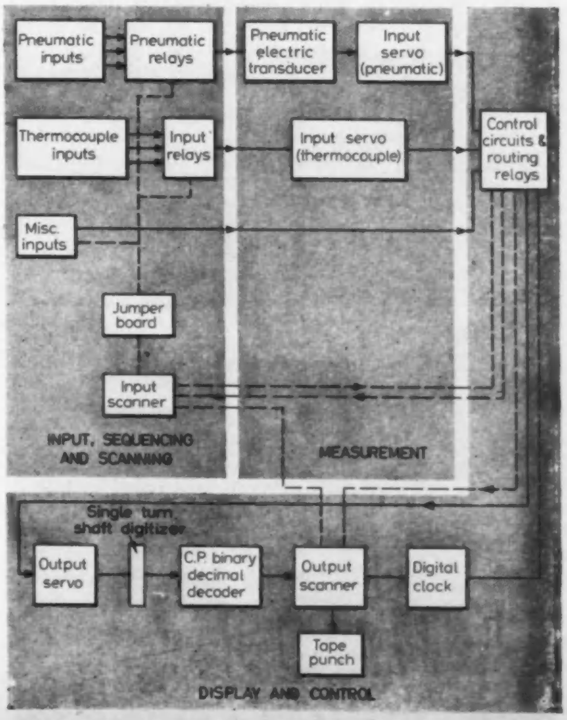
20ft trailer tours plants for investigations

DATA-LOGGING EQUIPMENT is not famous for robustness, and one would not normally think of humping it around from plant to plant; but this is what Imperial Chemicals aim to do with a unit specially built for them by Sunvic Controls. Housed in a 20 ft articulated trailer, this automatic data-handling equipment is completely mobile and has already travelled from Sunvic's Harlow factory to the ICI central instrument laboratory near Reading, on to a demonstration at the Plastics division at Welwyn and then to the Wilton works near Middlesbrough. So far not a single fault has appeared in the equipment. The idea is to use it for investigation and evaluation of process control problems in various plants, and the trailer is fitted with purging equipment and an air lock so that it may be used in a toxic or explosive atmosphere. At Wilton it is working with a Ferranti Mercury digital computer to formulate equations defining process relationships.

Requirements for the number and type of process variables to be logged are likely to vary considerably with each assignment and this is taken care of by a jumper board with sockets and leads; scanning capacity is fifty points (including tape identification and time) of which not more than twenty have been used so far, and they can be selected by the jumper from up to thirty-four thermocouple, thirty pneumatic and eight miscellaneous inputs. Many processes are affected by fairly slow disturbances and to study these scanning is on a fixed time basis at approximately three seconds a point.

For temperature measurement the thermocouple inputs can be either iron/constantan or chromel/alumel and signals can be routed to the most appropriate of four 300° C temperature ranges, starting at —150, 0, 200 or 400° C. These four ranges are available for any point and in each case temperatures are recorded as actual values in degrees centigrade. The millivolt signals from the thermocouples are referred to a cold junction which is stabilized by thermostats at 45 ± 0·1 ° C and switched in to the unit by input relays that have plated contacts on account of the low potentials. The switching sequence is controlled by uniselectors deriving time impulses from a decimal digital clock which also provides a visual display of time. The signal is then fed into an input servo consisting of a self-balancing potentiometer with a transmitting slidewire and tachogenerator feedback; this produces a relatively large a.c. output as well as linearizing the signal. After passing through the control circuits and routing relays it arrives at the output servo—similar to the input unit except that it incorporates a shaft digitizer—which converts the signal from an analogue to a binary number. The final step is a decoder which turns the binary

Data on up to 50 temperatures, flows, levels, pressures, etc are scanned and processed to a tape punch for use with a computer. Jumper board is used to select number of points and sequence of scanning required for each investigation



into a decimal number suitable for relaying through the output scanner to the tape punch. Two tapes are perforated in five-unit teleprinter code showing tape identification, time, point number and three digit value. One tape is used in the computer and the other passed through a tape reader for local readout and any necessary editing.

Complete scan given on demand

The equipment can cope with pneumatic inputs in the range 3–15 lb/in^2 for measurement of flow, level, pressure, etc, and they are recorded on an arbitrary scale of 0–999. Where the signal is proportional to the square root of the quantity to be measured—in orifice plate flow measurements, for instance—square root extraction is carried out in the logger. By using the jumper board, linear or square root extraction can be prescribed for any of the thirty pneumatic inputs.

Scanning is performed by a series of electrically operated solenoid valves that relays switch outputs in turn through a common manifold to a precision transducer; this converts the pneumatic signals to electrical inputs for the servo, which is again a self-balancing potentiometer. The eight miscellaneous inputs, for use with instruments like resistance thermometers and infra-red analysers, are displayed on single point potentiometric recorders. These have a range of 0–10 mV, but the range can easily be altered by plugging in a new bobbin. The instruments have retransmitting slide-wires and output can be printed out on a similar arbitrary scale of 0–999.

A complete scan of all signals can be obtained automatically every 6, 12, 24, 48 or 60 minutes, or 'on demand'. This 'demand' log is initiated by a pushbutton control which does not, however, override any logging sequence already in progress. In addition, by switching from 'automatic' to 'manual' any point can be selected for immediate print-out. Similarly it is possible to advance the scanners manually, step by step, or to repeat interrogation of any particular point. If simultaneous readings of several process conditions are required they can be obtained by routing these particular quantities to the potentiometric recorders. Then, when the scanner reaches a preselected point, all the recorders are automatically clamped so that their slide-wires cannot move. Retransmitted signals from these recorders are connected to the logger and scanned sequentially. After print-out is complete, the clamp is removed and they continue to produce analogue records.

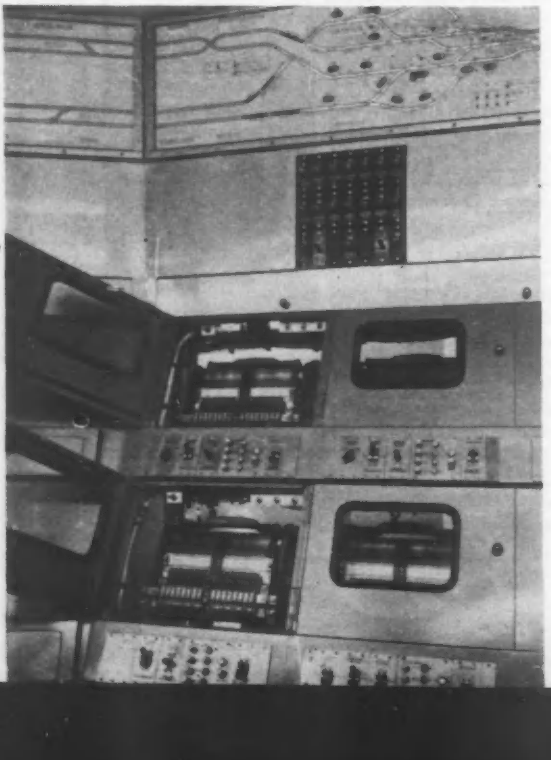
An extra thermocouple input point is provided for injecting a millivolt test signal from a suitable external source. This bypasses the cold-junction thermostat units. The pneumatic system can be tested by feeding in a metered, built-in 3–15 lb/in^2 signal to any input point. If a thermocouple becomes open-circuited, if the value of a variable goes beyond the full scale of that particular range in use, or if the decoder detects a fault, the presentation is changed to '. . .'. This enables any fault to be readily detected.

Control in Action is indebted to Sunvic for cooperation and a full description of the logger. It will be interesting to see what further uses ICI have in mind for it.

Auto-signalling on the Underground

London Transport machines to handle 1200 trains a day

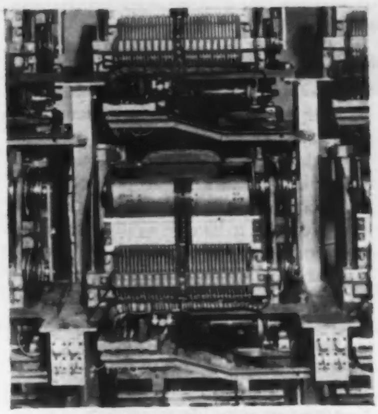
ANOTHER STAGE in London Transport's plan to introduce completely automatic signalling for the 1200 trains a day on the various routes of the Northern Line has been carried out with the installation of equipment at one of the Underground's busiest junctions. At Camden Town, signal cabin operators have now been replaced by 'programming machines' developed by London Transport, which work signals and points for a full day's tube service automatically after checking with the existing train describer apparatus.

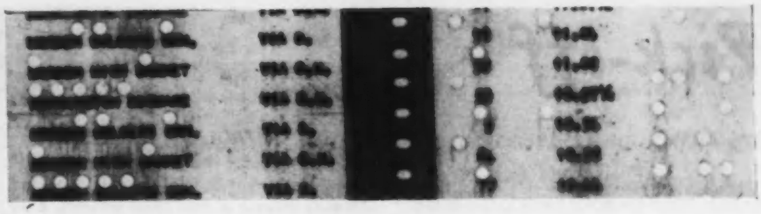


Separate machines are provided for each of the four junctions linking the Charing Cross, City, Edgware and Barnet/Mill Hill lines and they draw their information from punched plastic bands incorporating coded particulars of every train on the timetable in correct sequence. Each sequence machine, one for each track, has reference to a time programmer which gives warning if a service is late or sets alternative operation in motion if a train on a converging route is late. Repeaters of all the machines—exact duplicates—are located in the Signalling Supervision Room at Leicester Square, which is also provided with an illuminated diagram of the lines. Programme machines were installed at Kennington some months ago, and it only remains for a similar installation to be completed at Euston, which is due in a month or two, for automatic handling of all trains on the in-town sections of the lines to be achieved.

The plastic bands for the sequence programme machines contain typed details of each train due to pass over the section of line concerned on one day and the information is coded by holes punched between the rolls of typing. The presence or absence of holes affects the setting of the route and the operation of the signals for each particular train, and the passage of a train causes the roll to move forward one step to enable the information for the next to be read by the machine. Each band is some 8 ft in length and 8 in. wide and is wound on rollers mounted in a frame which can be easily put in or taken out of the machine. Changing rolls is necessary only when the service is altered, for example, on a Saturday or Sunday.

The Leicester Square control room is equipped with duplicates of all programme machines. In the event of a departure from the timetable, equipment can be switched to first-come-first-served working or routes operated manually from pushbuttons





Plastic rolls carry typed details of train destinations and routes, numbers and times, and the information is coded by punched holes. Contact probes press against the rolls and the presence or absence of holes effects setting of route and operation of signals; passage of each train causes roll to step forward so that information for the next train can be 'read'

A contact assembly, consisting of 30 contact probes, is pressed against the programme roll by a compressed air cylinder, and only those contacts which are aligned with a punched hole will make at any given time. The contacts read in this way the particulars of the first train to approach the junction and signal it in accordance with the information punched into the roll. The passage of the train energizes a relay which, in turn, actuates the operating relay for the programme roll driving motor and removes the feed to the contact valve. When the air is cut off, the contact assembly is lifted clear of the programme roll by a spring, and a relay which detects that the contacts are lifted is then energized. With the motor operating relay and contact lifting relay energized, the electric motor that rotates the rolls, driving in normal or reverse direction through magnetic clutches, starts to operate, moving the roll onward. It is stopped by a photo-electric cell which actuates a relay via a transistor amplifier circuit when a hole is located in the roll beneath it. It is not possible to drive the programme roll unless the contacts are lifted, and the roll can move only one step at a time in the normal direction, corresponding to one train movement. When the driving motor stops, air is re-admitted to the cylinder, which puts the contact assembly back against the roll. This sequence of operations continues throughout the working day until the last train steps the machine to the 'normalizing' position.

Trains held if machines disagree

The two time programme machines, one for northbound and one for southbound trains, carry similar information to the sequence machines, but are not stepped for the passage of each train. They are stepped after the lapse of time representing the interval between the previous train and the train due. This they count in half-minutes, half-minute impulses being obtained from a master clock. The programme roll, by means of a special code, indicates the number of half-minutes in the interval between each train and the next, and the time programme machine then counts these numbers of half-minutes before stepping. In this way, the time programme machine catches up with the sequence machine only at the actual time that the train is due, and it is by checking the coincidence of the two programmes that the time is determined. If the train is late the time programmer actuates a warning device.

When a junction is operating under programme machine working and the trains are arriving in accordance with the schedule the whole equipment runs entirely automatically; the machines check the train description as received on the train describer apparatus—which stores information recorded by a signalman at the train dispatching point—and provided that they agree the train is signalled. If a train describer disagrees with the timetable, the programme machine delays setting the route for half a minute while a warning buzzer is sounded at Leicester Square. If no action is taken by the supervisory staff the equipment switches over to train describer and 'first come first served working', ignoring the programme machines. The junctions continue to work automatically but the trains are signalled purely in accordance with their destination in the case of a splitting junction, and in accordance with their time of arrival for a converging junction. On the other hand, if the train description is in error the operator at Leicester Square can switch the equipment to follow the timetable by the programme machines and ignore the train describer.

If a train becomes more than two minutes behind the scheduled time as shown on the sequence programme machine, information from the time programmers sets off a warning at Leicester Square. At converging junctions the programme machine is arranged automatically to take account of a train on one branch being late, again by information supplied from the time programmer, and if the lateness exceeds a predetermined amount the machines will automatically send a train from the other branch forward, out of its turn. Where this is done the programme details of the train which is late are stored, and it is automatically signalled subsequently, so that the programme machine does not get out of step.

Other facilities at Leicester Square include provision for manual operation of the routes by pushbuttons, and four buttons for cancelling trains on each programme machine before the time for signalling that train has arrived. The method of carrying out this cancelling operation is that, when a message is received, that, for example, train 127 has been cancelled, the operator in charge of the supervision room at Leicester Square will look for train 127 on the programme repeater. The cancelling button 1, 2, 3 or 4, is then pressed, according to the position of that train on the programme roll. The button must be held until the lamp alongside it lights, to show that the cancelling operation has been duly stored. Once the button has been pressed and the lamp lighted, the equipment will count the trains as they pass with the stepping of the programme machine, and when the train selected by pressing the button is reached by the reading probes, the machine will step twice, thus eliminating the train from the programme.

After the last train at night the time programme machine takes complete charge so that the sequence machines are not put out of step by the passage of maintenance trains. Half an hour before traffic is due to start on the next day it energizes the normalizing relay, which starts a sequence of operations causing the motor to drive the roll in reverse until it reaches the starting position for the day's work. Another relay then arranges for the sequence machines to reset and step on to the first train position two minutes before the first train is due.

Pick-off

by *'UNCONTROLLED'*

THE Clean Air Act 1956 has now been fully in force for about two months, but at the time of writing no one has been convicted under it. This, I suspect, is because local authorities are not taking action against offenders until more time has passed. Certainly Britain's chimneys—both factory and locomotive—still seem to be disgorging plenty of smoke which to an untrained eye looks considerably darker than Ringelmann Shade 2, the darkest shade that the Act permits except during periods of soot-blowing—not more than ten minutes every eight hours. Although the Act does not specify a standard Ringelmann chart, the BSI has introduced one this year. This is intentionally very similar to a commercial chart produced in this country by the publishing firm of Charles Griffin for the last sixty years, and the notes (BS 2742) on the use of the BS chart call attention to it. The main differences are that the BSI prints its chart on card which is somewhat whiter than Griffin's paper, it puts Ringelmann Shade 4 at the top instead of the bottom of the chart, and it uses a 10 cm square instead of a 4 in. one for the printed grids. The last difference is puzzling; the BSI is not normally wedded to metric standards, and a difference of 0·16 in. in the width of the square can have no technical significance. I do not recall that Sir Hugh Beaver's Committee on Air Pollution made any pronouncement about the use of metric units, but perhaps this trivial shift towards them will not escape Sir Hugh's new study group on units for use in Britain.

But the unusual—and disturbing—thing about this is that in publishing a Ringelmann chart the BSI is not only laying down a standard for an instrument but selling the actual instrument itself. I know of no other British Standard that is itself an instrument—except, perhaps, the BS colour atlas, which is a reference standard and not a field instrument. The fact that the Ringelmann instrument is simple and produced from wood pulp and ink makes no difference to the principle. The right course surely would have been to have laid down how standard Ringelmann charts should be made (giving samples of card and printed grid if necessary) and left it to printers, publishers and instrument makers to produce them. Since 1939 HMSO has invaded the traditional domain of the commercial book publisher in great strength, with books and pamphlets on all kinds of subjects from portable tools to child welfare. I am assured that the publication of BS 2742C does not herald a comparable move by the BSI, but I do feel that it was unnecessary and that the BSI should stick to standards and codes of practice. As it happens, the commercial publisher has a good answer in this instance: BS Ringelmann charts cost 5s each, while Griffin's charge 2s 6d for three copies of their version.

LOOKING at a works where electrical control equipment was made, I saw a notice board displaying the words: 'Quality must be built into a product. It cannot be inspected into it'. This may be a widely used tag; I do not know, although I cannot remember meeting it elsewhere. Its philosophy is supported by a recent report from the Institution of Production Engineers entitled 'Quality—its Creation and Control'. But I could not help thinking that it was really at cross-purposes with modern ideas about automatic quality control. For it is by 'inspection'—to be more precise, by conducting physical and chemical tests—at stages in the manufacture of a product and by acting on the results of such inspection, that control of quality will be achieved automatically. With suitable feedback arrangements it should indeed become possible to 'inspect quality' into a continuously manufactured product. But, as it happens, the works in question produces mainly custom-built equipment—one-off, two-off, perhaps six-off—and the notice is clearly more applicable to a unit of this kind than to an automatic assembly line for radio receivers.

Nevertheless the 'quality' of a piece of electrical equipment is definable, measurable and controllable, even if the control implies an inspector walking back along the shop floor to tell someone that a wide-tolerance electronic component has crept into a circuit where a close-tolerance one is specified. Often real quality depends more on the design and test engineers than on the assembly operators on the shop floor. Perhaps only when a designer is his own executor is the notion of 'building in' quality really pertinent. Given the same material, the craft tailor will always achieve a better suit than the multiple-shop tailor who 'makes to measure' on a machine; he will produce a better suit because he retains the flexibility to alter its design slightly to fit the individual customer, while the work is in progress. This reminds me of another 'quality notice' which used to hang in a rather expensive tailor's shop that I occasionally patronized in the days before I was married: 'Memory of quality remains long after price is forgotten'. A useful approach for any salesman with something good to sell: I commend it to CONTROL's subscription department with a view to attracting some life subscribers.

'IT was serve, return, volley, crash—serve, return, volley, crash: the recurring decimal point, as it were, of a game reduced to the last stages of automation'. This is *The Times* lawn tennis correspondent describing the 1958 men's singles final at Wimbledon. It sounds frightening, and I prefer not to think for long about 'the last stages of automation'. The phrase awakes in me images that are horribly *Brave New World* and *To-morrow is Already Here*. But what is startling is the news that in the mathematics of advanced automation recurring decimals will not be enough to express awkward fractions—one will need recurring decimal points. Perhaps 'deuces' would be a suitable name for them, and in any event the designer of decimal/binary convertors will certainly want his wits about him.

I HOPE the following tale is still topical enough to amuse readers of *Pick-off*:

As the liner neared Port Said, two instrument manufacturers leaned against the rail of the upper deck and discussed trade. The first, a tycoon, was boasting about the amount of business he did in the Middle East. His flowmeters, pressure gauges, controllers and recorders were used in nearly every oil refinery, pipe line, power station and air conditioning plant from Teheran to Aden. When he finished, the other man grunted and said, 'Mine is only a small firm, but we make instruments that are really more useful to the Middle East at present than all your output'. 'What instruments are those?' snapped the tycoon. 'Revolution counters' came the laconic reply, as his companion turned away to go below.

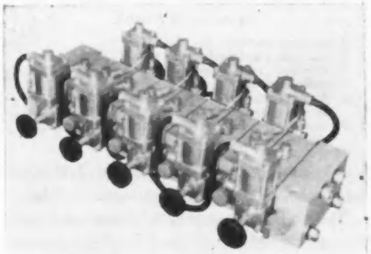
Thought for August—and every month: 'To the continuing explosive growth of control engineering' (Dedication of the *Control Engineers Handbook*, reviewed in last month's CONTROL.)

New for Control

A monthly review of system components and instruments

VALVE BLOCK simplifies piping

One solution to the multiplicity of piping in equipment using a number of control valves has been provided by Baldwin Instrument Co Ltd. Up to 12 valves are grouped together in one unit with supply and exhaust passages running the full length of the assembly. The main supply and exhaust is led to one end of the block and the individual supplies to each cylinder made from its associated valve. As an example of the economy afforded by this system, the 9-bank solenoid-controlled pneumatic unit shown has eliminated 17 connecting pipes.



This block has eliminated 17 connecting pipes

Tick **No 81** on reply card

HIGH-SPEED BATCH COUNTER display on dekatrons

A fully electronic high-speed batch counter with the count displayed on dekatrons has been developed by Elcontrol Ltd. A preliminary version was shown at the 1957 IEA exhibition but this version has apparently been improved. The maximum counting rate is 500 per second with a 3-millisecond recovery time between batches. The counter can be used in a variety of ways including its employment as a timer.

Tick **No 82** on reply card

HAYNES MONITOR thickness control of plastic tube

The wall thickness and concentricity of plastic tube can be measured as it is extruded with an instrument recently announced by Haynes and Haynes Ltd. The Haynes monitor, as it is called, consists of a detector head and a control cabinet. The plastic tube passes through the detector head and the thickness is shown on a meter in the control cabinet. The meter has controls which can be set for upper and lower limits, and any deviation from these limits will actuate an alarm. The concentricity of the tube bore is checked by scanning the circumference of the tube with the detector head.

Tick **No 83** on reply card

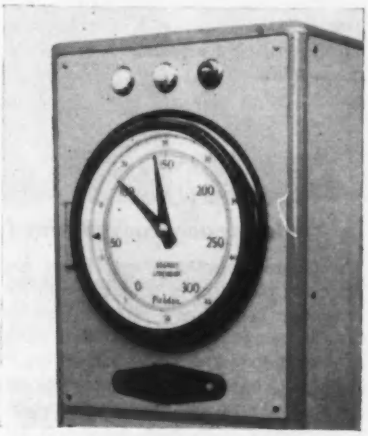
MINIATURE RELAYS robust enough for industry ?

A new range of miniature relays has been marketed by Londex Ltd. Although they are miniatures, it is claimed that they are still robust enough to go with a product required for industrial use. The LOK relays are totally enclosed, plug-in models.

Tick **No 84** on reply card

AUTOMATIC SCANNER aids temperature control

An automatic temperature scanner (type BB1) has been developed by Fielden Electronics Ltd. The temperatures from 50 thermocouples can be displayed, one at a time, on a 2 ft diameter dial. One pointer indicates the number of the thermocouple being examined and another pointer indicates the temperature. Each thermocouple has its own set point, and this is shown by an arrow moving round the outside of the dial. Each set point can be put in one of three tolerance bands, and any deviation of the temperature from its tolerance will cause an alarm to be set off. Normally the equipment will scan the points in sequence, but any tolerance deviation will stop the operation and one of three tolerance lamps will be lit. The scanning can be restarted by bringing the temperature within the desired band, or by a manual control. Facilities are provided for stopping and starting the scanning on any particular point.

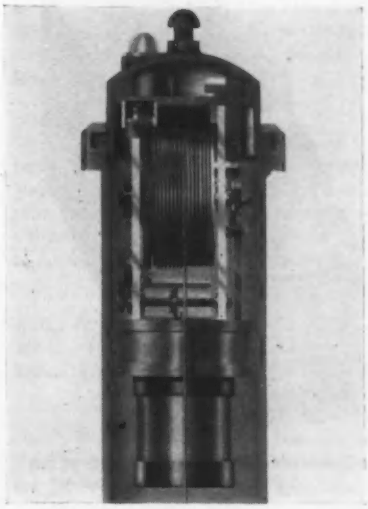


The scanner has a clear dial with three lamps to indicate which tolerance band has been exceeded

Tick **No 85** on reply card

WINDING MECHANISM uses new stepping motor

A new reactor control rod winding-mechanism designed by the Sperry Gyroscope Co Ltd is to be displayed on their stand at the Atoms for Peace Exhibition at Geneva. The motive power is supplied by a d.c. stepping motor which has a high torque and a digital following characteristic. An eddy current brake is fitted and a number of safety features are incorporated.



A winding-mechanism for a reactor control rod

Tick **No 86** on reply card

LINEAR POTENTIOMETER gives smooth output

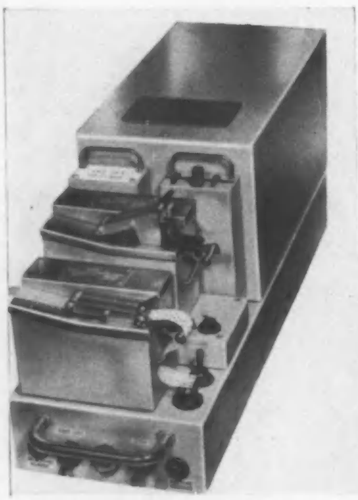
Another new Muirhead product with a 26 V 400 c/s supply, is the size 11 linear. The instrument has a voltage output proportional to rotor angle, up to a maximum of

42·5 V. The linear relationship of ± 1·4 pc extends over the range ± 85 deg from the zero output position and gives a smooth variation of voltage devoid of any fluctuations due to tooth ripple.

Tick **No 87** on reply card

TAPE READER automatically numbers messages

A new tape reading and auto-numbering apparatus has been developed by British Telecommunications Research Ltd for the Automatic Telephone and Electric Co Ltd. This machine will automatically number telegraph messages on high-speed punched tape systems. Two operating heads are provided; as soon as one head has finished reading one tape then the other takes over with another tape. The unit also includes an automatic numbering device, a 100-character test message sender and two 40-character message senders. The first of these 40-character senders is used for the station call sign and the other provides for the automatic transmission of routine traffic. An automatic timing device permits the



The tapes pass through the leads at the front of this compact unit

terminal unit to transmit test messages at predetermined times so as to test the circuit. The equipment is suitable for operation on 100–150, 200–250 V, 50–60 c/s.

Tick **No 88** on reply card

MIDGET POTENTIOMETER plus useful attachments

Three useful fittings and a midget potentiometer have been shown by Wirepots Ltd. The diameter of the potentiometer is 0·92 in., the length of the body 0·67 in., and the weight is 12 g. The resistance is up to 50 000 ohms linear. The indicating dial has been developed primarily for use with 10- and 15-turn helical potentiometers, but can be supplied for other applications. The spindle locking device has been designed to lock the spindles of preset potentiometers. The flush lock fitted to a preset potentiometer will bring the end of the spindle flush with the panel and will also lock the spindle.

Tick **No 89** on reply card

ELECTROMAGNETIC COUNTER silent, long-lasting

The Elmeco electromagnetic counter can count accurately at a sustained rate of 30 impulses/second, or up to 60 impulses/second for limited periods. The number drums are driven by a plastic belt from a stepping motor, and this is claimed to give a silent operation. It can be supplied for 5, 6 or 7 figures and the guaranteed life at 30 impulses/second is 300 million counts.

The counter is made by Elmeco AG of Zürich, and inquiries about it in this country can be accepted by Inglis Knibber & Co.

Tick **No 90** on reply card

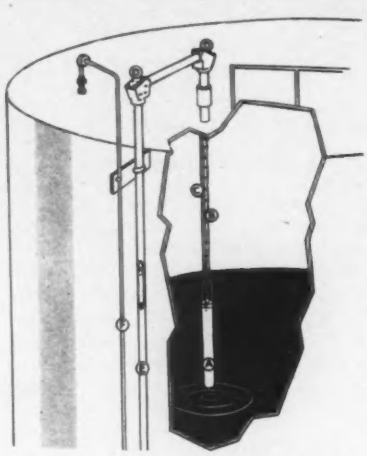
SWITCH INDICATOR shows position clearly

A switch position indicator has been developed by the Hasler Telegraph Works Ltd. It gives the information in the form of a semaphore signal on a large dial; one direction gives the open position; at right-angles to this it indicates the closed position; and at an angle mid-way between the open and closed positions it shows a defective circuit. The indicator is made in a variety of sizes and is available for operation on a.c. and d.c. supplies.

Tick **No 91** on reply card

ELECTRONIC TANK GAUGE extreme accuracy attained

The Gilbarco electronic tank gauge has measured the level of a liquid with an accuracy of better than ± $\frac{1}{16}$ in. on installations in America. It can be installed in tanks of all types up to a temperature of 425 deg F and a depth of 1000 ft. The sensing element is a small cylinder, at the lower end of which is an antenna, $\frac{3}{8}$ in. long, dipping in the liquid. The antenna emits radio waves at a frequency of 160 Mc/s, which are reflected from the liquid surface and picked up by a coil. If the liquid level changes, then the impedance presented between the antenna and the coil will change. This impedance change is detected by an electronic servo-mechanism, which will control a steel band in such a way as to keep the antenna immersed in a fixed depth of liquid. A mechanical indicator attached to the steel



The level indicator as it might be installed in a tank

A sensing element
B stainless steel perforated tape
C shielded radio frequency cable
D pulley boxes
E 2½ in. stand-pipe which leads to electronic servo control unit
F conduit for leads from averaging resistance thermometer

band shows the level of the liquid. There are facilities for remote transmission of data.

The Gilbarco gauge is to be manufactured and marketed by Firth Cleveland Instruments Ltd under licence from the Gilbert & Barker Manufacturing Co of Massachusetts, USA.

Tick **No 92** on reply card

UNIVERSAL BEVEL GEAR combines two advantages

A novel form of universal bevel gear has recently been put on the market by Standage Power Couplings Ltd. It combines the advantages of constant velocity with the ability to transmit rotary movement at angles from zero to 90 deg or from any point within a full circle.

Tick **No 93** on reply card

AUTOMATIC VOLTAGE REGULATOR feedback prevents hunting

A new type of automatic voltage regulator is to be produced by the John Morris Electrical Engineering Co Ltd. A balanced armature is supported on ball races between the poles of a low-hysteresis magnet. The armature is restrained by an adjustable spring and will rotate according to the variations in the output voltage applied to the magnet. As it rotates it will turn two rollers over a number of fixed contacts, each of which then connects a resistance in parallel with a set resistance. In this way

the included resistance in the excitation circuit can be varied. One feature of the regulator is a first derivative negative feedback loop to discourage hunting. The addition of a number of external components can convert the unit from single to parallel running.

Tick **No 94** on reply card

CONDUCTIVITY CONTROLLER
designed for rugged use

The Unicon DSI 1 is a detergent strength indicator and controller. The unit is designed for use in the laundry, dairy, brewing and textile industries, or in any process where changes in conductivity of a solution are indicative of deviations from a desired standard. An example is in the continual checking of rinsing waters to ensure the removal of soap and detergent. The immersion type electrode has a diameter of [illegible] in. and in the standard version is situated at the end of a galvanized steel tube of similar diameter, available in lengths between 4 in. and 6 ft. The control box has facilities for warning and remote indicators. The DSI 1 has been introduced by Universal Control Equipment Ltd.

Tick **No 95** on reply card

DISPLAY TUBE
optics instead of electronics

An in-line digital display tube employing an optical projection system with twelve lamps has been introduced by Counting Instruments Ltd. The illuminated figure is 1 × [illegible] in. and the standard unit can be supplied for 6, 12 or 24 volts.

Tick **No 96** on reply card

HALF-WAVE RECTIFIER
large-hearted performance

A silicon half-wave rectifier has been released by the Siemens and Halske AG. The body of the rectifier is 7 mm in diameter and approximately 17 mm in length. The rectifier has a peak inverse voltage rating of 750 V and is rated for 0·4 A d.c. with a capacitance load and 0·5 A d.c. with a resistance load. The UK distributors are R. M. Cole (Overseas) Ltd.

Tick **No 97** on reply card

PEOPLE IN CONTROL

The Consolidated Pneumatic Tool Co announce the appointment to the new executive position of personal assistant to the managing director, of **Mr J. L. Ritchie.**

The Institution of Production Engineers announce that the **Earl of Halsbury** will remain in office as President for a further year. **Mr H. W. Bowen,** Chairman of Damic Controls Ltd, has been elected Chairman of the Council for the coming year and **Mr R. H. S. Turner,** director and works manager of Metropolitan Vickers Electrical Co Ltd, Vice-Chairman.

Mr J. Walker has been appointed to a senior post in the Engineering Division of the Sperry Gyroscope Co to strengthen their team of engineers engaged on projects in the nuclear field.

Sunvic Controls Ltd announce the appointment of **Mr R. W. Pocock** to the commercial dept for duties in connexion with Pulse Height Analysers and Electronic Instruments. **Mr J. B. Marrison** has been appointed as a special representative for process control instruments.

LORD HALSBURY

J. L. RITCHIE

Racal Engineering Ltd have appointed **Mr E. T. Harrison** to the board of directors. He will continue to act as company secretary.

Lieut-General Sir John Evetts has been elected Chairman of Rotol Ltd and of British Messier Ltd. **Mr C. J. Luby** has been appointed Managing Director of the two companies.

SIR J. EVETTS

C. J. LUBY

Mr Raymond Barrington Brock of Townson & Mercer Ltd took office last month as President of SIMA.

Mr K. S. Estlin has been appointed cable sales manager of Siemens Edison Swan Ltd. He will be succeeded as London district manager by **Mr J. A. E. Trinder.**

West Instrument Ltd announce the appointment of **Mr W. Proudfoot** as Manchester area representative for the company. **Mr J. C. Driver** has been appointed Chief Inspector.

EMI Electronics Ltd announce the appointment of **Mr K. Elphinstone,** previously with Marconi's, as Export Manager. He takes up this post following **Mr R. W. Addie's** recent appointment to the board as Marketing Director.

Mr E. F. Dunkin has been appointed by Venner Electronics Ltd as UK Sales Engineer, responsible for technical liaison and sales promotion of the Venner range of transistorized packaged units and test equipment.

Ketay Ltd announce the appointment of **Mr G. E. Sugden,** previously with the Sperry Gyroscope Co Ltd, as Sales Manager

Mr P. W. Faulkner, General Manager of the Chemical and Metallurgical Division of the Plessey Co Ltd, has been appointed a director and General Manager of Plessey International Ltd. Mr Faulkner remains an Executive Director of the Plessey Co Ltd.

J. WALKER

R. B. BROCK

NEWS ROUND-UP

Control signals for sale?

In future, control, as well as computing, may become a saleable commodity following the advances of the logical designers in effectively enabling computers to handle several programmes at once. M. V. Wilkes, giving his presidential address on 'The Second Decade of Computer Development' to the British Computer Society recently, foresaw the possibility of laboratories or workshops feeding information at intervals to a central computer which would use a few milliseconds of its time periodically to take decisions required for determining the future course of a process and supply the necessary control signals. Break-in operation—the use of a machine concurrently on a number of different jobs, dividing its time between them according to a laid-down order of priority—will not only be desirable, he thought, but necessary if the new and very fast machines now being designed are to be efficiently loaded. At present occasions arise when a central computer is kept waiting because of slowness in the various pieces of peripheral equipment. With break-in facilities a single central computer could turn its attention as required from one to another of a number of distinct peripheral units. The order of priority would not necessarily correspond to the order of importance—for example a computer might be engaged on production calculations and at the same time be used for testing a new programme. In this case the programmer would be able to seize the machine whenever he wanted it; afterwards it could go back to routine calculation. Perhaps in the future, speculated Dr. Wilkes, large-capacity computers would be provided as one of the central services for a large organization. In an engineering group, for instance, it might be used for scientific calculations in the research department, work out problems for the designers and at the same time be engaged on inventory control, scheduling of production, preparation of the payroll and general accounting; in addition to all this the computer could provide automatic control for say a group of rolling machines and a fully automatic mass spectrometer in the physical laboratory.

The realization of such a happy state would depend very largely on the intrinsic reliability achieved by the next generation of very fast computers, he stressed. Transistors have proved themselves and will certainly help here; their higher reliability should lead to the use of more complex data-processing systems than are at present envisaged, and it has become apparent in the last year or two that they will enable another step to be taken towards higher speeds.

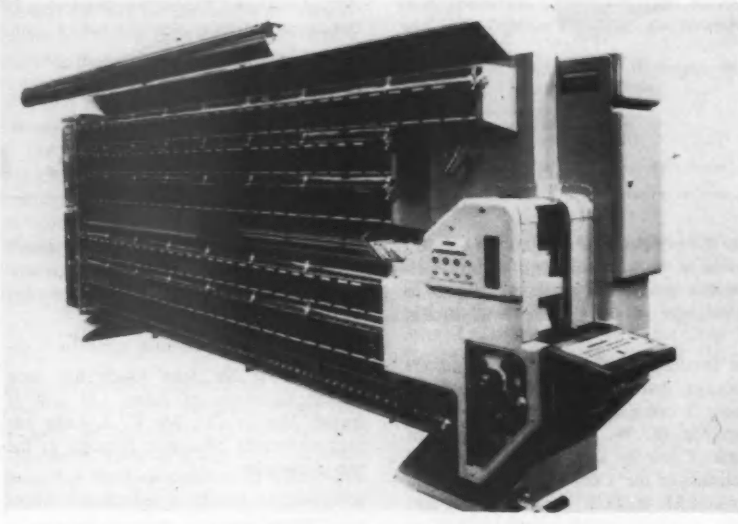
The development of data processing as a subject, Dr Wilkes added, has tended to merge commercial and technological management. Nowadays the same fundamental problems of control—how to define and measure efficiency, and how to use the measurements to improve it—are found in a continuous gradation of situations between the extremes of pure engineering and pure commerce. At one end of the scale would be a computer used in connexion with the control of a chemical plant; at the other, efficiency in a clothing factory would depend primarily not on technical considerations of how to cut the cloth, but on the proper organization of work flow, choice of batch sizes and stock control of raw materials and finished products. But the same ideas, he concluded, were applicable to a factory of any kind, whether operating a continuous or batch process.

GPO starts electronic sorting

An electronic letter sorter which will enable a skilled operator to cope with over 4000 letters an hour has been handed over to the Post Office at the Thrissell Engineering Company's works at Bristol. The first of twenty ordered for extended trials throughout Britain, the £15 000 machine has the added advantage that letters can be directed into 144 separate boxes instead of the usual 48 associated with manual sorting. Seated at one end of the 7 ft long machine, an operator will be able to sort letters as fast as he can read them. This has been found to be about 70 a minute which is still well within the speed capacity of the machine. It has a time cycle rhythm, but the operator can key at random and the machine automatically compensates and adjusts the timing to synchronize as necessary.

Letters are automatically fed to a viewing window and the operator simply notes the destination and presses one of twelve keys with his left hand and one of a similar group with the other. The letter is then fed to a waiting compartment which gives the operator a chance to rectify a mistake: the destination is 'remembered' electronically, and if he realizes he has misread the address a cancel key can be pressed. If not the letter is dispatched into the machine conveyor system just as the next letter is read and coded. The memory unit now transfers its information to banks of mechanical switches which trigger diverters and direct the letter first to the correct row of boxes and finally to its appropriate box. A changeover arrangement similar to that used in computers allows a choice of four different sorting combinations to deal with, say, two incoming and two outgoing mails, and it can be operated in less than a minute.

Developed in collaboration with Electronic Instruments Ltd of Richmond, the sorter uses 270 valves—mostly of the cold-cathode type—and weighs just under three tons. It is an improved version of an experimental Post Office prototype.



Using the new GPO electronic sorter an operator can direct letters into 144 separate boxes as fast as he can read the addresses in the viewing window

Computer show to aid executives

More than forty British manufacturers of computers have taken space in the first Electronic Computer Exhibition and Business Symposium, to be held at Olympia in London from 28th November to 4th December. It is being organized by a joint committee of the Electronic Engineering Association and the Office Appliance and Business Equipment Trades Association at the instigation of the National Research and Development Corporation. Main emphasis of the symposium will be on the value of the computer as an aid to management and it will consist of papers designed to bring executives up to date on practical experience gained in the installation and operation of British computers and data-processing systems.

An associated symposium organized by the National Physical Laboratory will be held at Teddington from 24th to 27th November, and one of the highlights here will be a paper on the NPL's work on learning machines (*News Round-up*, July).

Control made easy?

A relatively simple machine tool control with a punched card information storage system is now in use in industry. Developed by Ekco Electronics it provides automatic co-ordinate setting and can be fitted to existing as well as new machines. Mainly resistors and relay circuits are used with no electronic valves and Ekco say that its maintenance is within the province of the works electrical engineer and requires little special training. It is designed to reset automatically a 10 t.p.i. lead screw to $\pm 1/500$ of a single turn representing 0·0002 in. linear movement of the work table; as the final approach is always from the same direction the effects of backlash are avoided. The newly developed punched-card information storage system allows information for up to 23 holes to be contained on one card, so that the system can be programmed for sequential operation until all work with a particular drill has been completed.

BTM increases computer training

A new Hollerith residential computer training centre was officially opened at Bradenham Manor near High Wycombe on 24th July; dealing mainly with computer programming and refresher courses on the general-purpose electronic computer, it supplements the resources of the Hollerith Computing Centre in London, which is concerned mainly with demonstrations of computers in their various aspects and is non-residential.

Opening the centre at Bradenham, Lord Halsbury, Managing Director of the National Research Development Council, gave a sketch of the developments leading to modern computers; he said that tracing the evolution of the punched-card information-handing devices forward in time and working backwards from the electronic digital computer seemed to show a meeting in a 'somewhat hazy' atmosphere of cross-fertilization between ten and twenty years ago. Attempts to discover who really invented what were difficult, though the first all-electronic stored programme computer with punched-tape input undoubtedly worked first in the laboratory of Dr Wilkes (CONTROL editorial consultant) at Cambridge.

FOOD

New Plant cuts labour by 88pc

A new malting plant opened recently at Knapton in Yorkshire can produce 12 000 tons of malt annually—enough to make over twelve million gallons of beer. It is the largest fully mechanized malting plant in Europe, and less than twenty workers will run the maltings instead of the 180 or more which, it is estimated, would be needed using non-mechanized plant.

Hot air for the kilns—used for drying and airing the malt after germination—is produced by oil-fired furnaces, which are automatically controlled on the basis of relative humidity of the air leaving the kiln tops. In the germinating compartments close control of temperature is important and automatically controlled refrigeration plant is incorporated.

CHECKING BISCUIT PACKETS

After falling from a pipe inside the tube of wrapping paper biscuits are bagged in front of a radioisotope source at Meredith & Drews. Any bag not full is rejected through a trapdoor in the chute actuated by an IDL counter

RAILWAYS

ATC to be stepped up

Published on 24th July, the Ministry of Transport report on the Lewisham train crash last December concludes that the accident would have been prevented by automatic train control of the warning type, and Sir Brian Robertson, British Transport Commission Chairman, has promised that the installation of ATC equipment will be accelerated. The use of radio and radar is not contemplated, says the report, because of the large number of train movements and signal boxes involved. It was used in marshalling yards and other places where misunderstandings would cause no danger to the travelling public. Investigations into the use of electronics 'was proceeding'.

The BR system of ATC works on distant signals only from two magnets fixed in the centre of the track 200 yd on the approach side. The first is a permanent magnet and the second an electromagnet controlled by the aspect of the signal. Equipment fitted on the locomotives responds to the field and audible warning is given in the cab if the signal is at caution; if it is ignored brakes are applied automatically.

AIRCRAFT

Exports up as Farnborough nears

Acceptances of overseas invitations to the Flying Display and Exhibition have reached a new high, and it looks as if last year's record attendance of 7000 overseas guests will be exceeded comfortably. As a background to this, recently released figures on exports are interesting: aviation sales overseas for the first six months of this year are up 46 pc on January–June 1957, bringing the total since the end of the war to over £700 million. More than £1 million worth of instruments were exported during January–June this year.

The guided missile park will be nearly half as large again as last year's. One reason for the extra space is that live demonstrations will be staged with some of the weapons—crews will show launching preparations and how certain equipment is used in an operational role: everything, in fact, but the actual firing. Exhibits will include the Bloodhound—the first surface-to-air guided weapon to go into service with the RAF. It is a joint effort by Bristol Aircraft and Ferranti. As a target manoeuvres, the Bloodhound alters course and continuously aims ahead of the target so that interception takes place at the earliest possible instant after launching.

Components and systems on show will range from machine tool controls by Ferranti and Ekco Electronics to new Marconi radars and doppler navigators. Demonstrations will include such various apparatus as a new Wayne Kerr vibration meter—used

for monitoring shaft vibration in an electric motor and protecting it from damage by causing a switch off when vibration exceeds a predetermined amount—and the Ekco v.h.f. automatic direction-finding equipment. This gives automatic display of the sensed bearing of transmissions on any one frequency from 118–132 Mc/s and uses a rotating aerial.

UK to instrument new NATO plane

Recent news that over 300 Italian designed Fiat G91 lightweight strike fighters are to be ordered by NATO powers highlights a feature of production cooperation between North Atlantic countries. This first of the post-war generation of Italian jet fighters to go into full-scale production is to be largely instrumented, and will be powered by British equipment. Of particular interest among the instruments is the miniature 2¼ in. turn and slip indicator which is designed to operate in a temperature band ranging from —55° to 70°C. The electrically driven gyro motor is fitted with a centrifugal governor developed by Kelvin and Hughes Ltd, one of the Smiths group. Large changes in the rotor speed would produce indication errors in the instrument and the centrifugal governors hold the speed to within 104 r.p.m. of the normal 5200 r.p.m. in a voltage range of between 20 and 29 volts. Current is fed to the armature through brushes on an 18 segment commutator via the governor contacts. When the rotor speed rises above a preset level and the governor contacts are broken the armature continues to be fed through two 470 ohm resistors which are shorted out when the contacts close again. The resistors prevent large speed surges and help to prevent arcing at the governor contacts.

Before the speed of the gyro rotor can fall below a limit which would render the turn and slip indicator unreliable an 'Off' flag appears on the instrument face. The flag is mounted on a stirrup which carries a permanent magnet, and this is set close to the outer face of the gyro rotor which has a copper ring spun into it. When the rotor is at rest the South pole of the stirrup magnet is attracted to the North pole of the motor field magnet causing the 'Off' flag to show on the instrument. As the rotor gathers speed the stirrup magnet generates eddy currents in the copper ring which eventually overcome the polar attraction and move the stirrup assembly upwards, thus lifting the flag out of sight.

PAPER

New ideas in board production

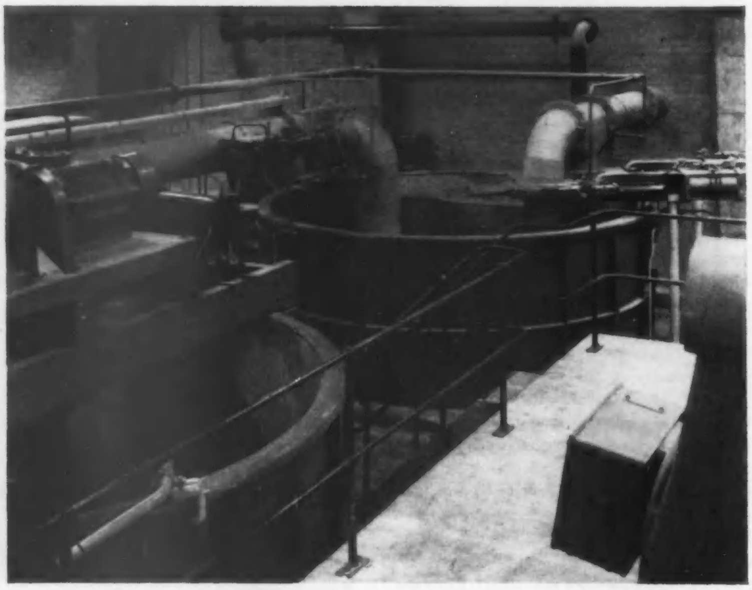
The output of board at Colthrop Board and Paper Mills Ltd at Thatcham in Berkshire will be doubled by the machine installed as part of a new £5 m mill. It is designed to produce a continuous highway of board 110 in. wide and about 160 miles long every day at peak capacity, and a spokesman at Colthrop's claims that folding cartons produced from the board are used by almost every industry in the country. Most of the instrumentation in the mill is pneumatically operated using compressors manufactured by Broom & Wade Ltd, and variables indicated, recorded or controlled include consistency, flow, temperature, liquid level, pressure and substance, using instruments of a variety of companies.

Consistency control—maintaining the necessary percentage of pulp to water—is carried out using a constant head tank of stock: a sample is fed into a stand pipe and allowed to flow through a 1½ in. diameter viscosity tube. This causes a build-up in the stand pipe depending on the consistency, and the level is measured either by an air-purged bubble tube or a Taylor pressure transmitter. Output actuates a Foxboro controller which operates a valve to add dilution water when necessary. Remote indicators enable operators in various parts of the preparation plant to see what is happening.

Controlled addition to stock of various liquid chemicals is by means of 'measurement' preset meters working in conjunction with air-operated Saunders valves; a large number of Rotameters are also used for chemical addition and water flow to glands of pumps, etc. Water flows are measured by Taylor differential pressure transmitters working with orifice plates and Bristol recorders, and all steam gauges are indicated and recorded by Bailey meters.

Air temperature in various parts of the mill and to the board machine is closely controlled to eliminate condensation, and the steam to the air heaters is regulated by proportional controllers in conjunction with Stabilflo valves. Stock temperatures are recorded automatically, and one chart shows conditions in eight different screen outlet mixing boxes. An Arca control valve is used to provide a constant steam pressure and thus temperature to the board machine drying cylinders, and remote control is provided from the operating floor of the machining house next to the main drying section. The machine presses are pneumatically loaded for mechanical extraction of water from the board and independent pressure regulators and control panels, including load gauges, are mounted adjacent to each press.

Installed before the first pre-drier and after the calenders, Baldwin radiation gauges continuously check the board substance on the machine and at each position there are three measuring heads across the width of the machine: recording instruments give a clear indication of any change of basic weight so that immediate correction can be made.



Pneumatically controlled valves operate the duo-cycling chests in Reed Paper group's new £5 m board mill at Thatcham

An interesting control installation is used for the preparation of the 'Liner' or pulp stock. Three hydrafiners, each driven by 350 h.p. motors, are controlled from a special desk manufactured by the Igranic Electric Co. They are fitted with Duotrol automatic plug controls and from the remote control equipment it is possible for the operator to set them so that the units run on predetermined electrical loads. Recording ammeters and depth gauges give a clear picture of the work done on the stock, while a preset counter automatically controls the number of passes the stock makes through the hydrafiners.

—NUCLEONICS—

US advance in reactor control

A giant fuel handling mechanism constructed by the General Electric of America's Atomic Power Equipment Department for the Enrico Fermi Atomic Power Plant near Monroe, Mich, USA, will make possible the first near-automatic refuelling of nuclear reactors. By means of accurate positioning mechanisms, this remote, 34-ft high, 8-ton manipulator will be used to replace fuel elements, breeder elements of depleted uranium, and control elements located in more than 600 cells in the honeycomb shaped reactor core.

Because of its location inside the reactor enclosure, the manipulator will be controlled electronically from a central panel in a separate building. Once the controls are actuated, replacements for spent fuel elements, breeder and control elements will be fed to the manipulator through an access chute into separate receptacles on a turntable. This will then revolve to place these elements within reach of the manipulator, and charging will be accomplished by closely controlled movement of the offset automatic manipulator across the face of the core to a selected square in the core honeycomb. Spent elements will be removed by placing them on the turntable and rotating them to the access chute where they will be mechanically lifted out of the reactor enclosure. In addition, the manipulator is linked with a reactor radiation monitoring system so that any unexpected increase in nuclear reactivity during core loading operations would automatically trigger the removal of key fuel elements to shut down reactor operation.

REMOVING CARTRIDGES BY REMOTE CONTROL. A new AEA-designed robot, carrying a TV camera and grab, can be operated from the top of a reactor biological shield to search for and pick up any radioactive cartridges lodged in the discharge void. The grab and camera are mounted on a boom capable of rotary and lateral movement which is lowered into the void

—STEEL—

New aid to process control

Following an extensive survey made about 18 months ago on fumes emitted from open hearth furnaces the British Iron and Steel Research Association has designed a sampling apparatus for the rapid measurement of red iron-oxide fumes emitted with hot waste gases; an engineered version by the Longworth Scientific Instrument Co now results in LISA—Longworth Isokinetic Sampling Apparatus—and parts have already been ordered by Colvilles Ltd, who have been following their own line of research.

Primarily the apparatus is a guide to grit, dust and fuel emission dangers from the nuisance-value angle to offer protection against complications with the authorities, but it should have considerable value as an aid to process control. A probe faces directly into a gas stream and a sample is withdrawn isokinetically, i.e. it flows into the nozzle in the same direction and with the same velocity as the local undisturbed gas stream so that dust content accurately represents that of the main flow. The sample is then drawn through a weighed filter and piped through a cooling unit to ensure that corrosive liquids are not condensed in the remainder of the sampling train. Two gas-tight vane pumps, equipped with by-pass valves and connected in parallel, then expel the filtered and cooled sample through a flow-rate indicator and an integrating meter: this avoids determining the volume of the sample by integrating a flow-rate/time diagram. The filter is then reweighed and the concentration obtained by dividing the mass by the volume of the sample. In order to sample isokinetically, the gas velocity and temperature in the stack are measured with a combined pitot tube and pyrometer and indicated on gauges in the control unit. Two column tables are used which relate the gauge reading to the isokinetic sampling rate, which is maintained by operating one of the by-pass valves. This simple method of flow rate control is made possible by placing the meters after the pumps where gas pressures and temperatures are virtually constant. Rates of gas and fume emission from steel-making processes can vary rapidly and LISA's main advantage lies in the speed with which samples can be taken. Filter changing is said to take no more than about ten seconds.

—CARS—

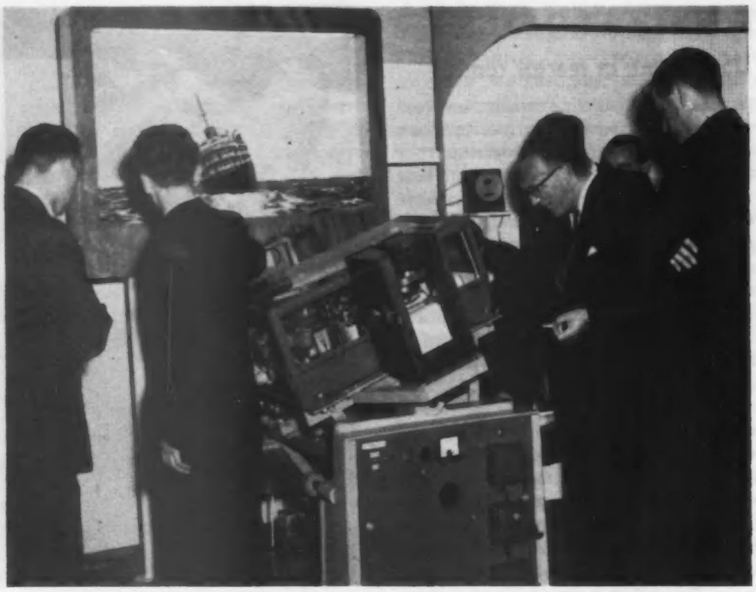
Punched cards solve Ford problem

Production of car cylinder blocks, heads and tractor parts is now in full swing at Fords new £7½m Thames foundry. The whole plant is highly instrumented and output of the 1800 operators is said to be twice that which could be obtained with conventional plant. One of the most interesting features is the punched card system for core sand control developed in collaboration with Sinex Engineering. The problem was to produce 350 tons of bonded core sand a day, with a maximum time allowance of only three minutes for the proportioning of an individual mix of approximately one ton, and the bonded core sand was required to be accurate within 1 pc of the specification. Handling equipment was required which would convey the core sand to the core blowing plant at speeds up to 7000 ft/min. Sinex Engineering were approached and after consideration offered an installation incorporating four automatic batch weighing groups programmed and controlled by a punched card system as the only solution, with a pneumatically operated conveyor.

The punched card passes under electro-sensitive feelers which transmit impulses to preselector units fitted in the scale dial heads and the 12 volution counters for the liquid meter pumps of the Sinex batch weighing system. This presets the required quantity of the first ingredient in the dry and liquid groups. The cycle is so timed that weighing of the bulk dry materials and the dry additives starts simultaneously; delivery of the metered liquid constituents is delayed to the mix muller after the dry mix has commenced. The Vibratory feeder catering for the bulk materials is started by an impulse from the Oerlikon punched card controller and

begins delivery, at high speed, of the first ingredient—normally Aylesford sand—to the weigh hopper. As the weight approaches the preset value, a detector, actuated by the scale pointer, operates relays which change over from fast to slow speed on the vibratory feeder, reducing the delivery to a trickle. At the instant when the correct weight has been delivered, a further relay operates, breaking the power supply to the feeder and extinguishing the appropriate 'weigh in progress' lamp on the panel. A signal from the controller now sums the weight of the first and second ingredients—Garside sand—and presets the required total weight at the scale dial head. Sand from the Garside container is then vibrated to the sand hopper and controlled to the finish point as before. In parallel with these operations the additive materials are similarly weighed.

During the weighing cycle the metering pumps transfer the preset volume of water and two oils from the storage tanks to the two blow tanks. When the start button on the mixer control panel is pressed the dry materials are discharged into the muller and the mixing cycle commences. After a preset period of ten seconds the blow tanks discharge the liquid additives, under air pressure, into the muller. The final mixing sequence is timed and monitored by the mix timer. Orange lights on the mixer panel, indicating that dry materials, oil and water are directed to the mixer, are illuminated in succession to show the completion of each operation, and each cycle is timed on the appropriate timer. When the mixing is complete the mix is automatically discharged to the turbo-drive system, delivery being indicated by the fourth orange lamp and timed by the fourth timer.



SHIP STABILIZER CONTROL. System used on *Queen Mary* was demonstrated recently by Muirhead & Co on their analogue rolling table; this can simulate roll—with or without stabilization—for ships of almost any size

Lower costs in making cars?

Nearing completion at CVA's No 6 factory at Hollingbury, Brighton, is a new 51-station transfer machine. With a 140 ft transfer guideway it is the largest machine of its kind yet built in Britain. In all, 37 different machining operations—milling, drilling, tapping, and boring—are carried out on it. Only six men are needed to operate the transfer machine. CVA have not disclosed either the component it machines or the customer who is buying it, but it is most likely that it will be used for machining cylinder heads by one of the large British automobile manufacturers. The control is electrohydraulic, with limit switches and relays controlling the valves which operate the hydraulic cylinders. The first cuts on a component passing through the machine are being taken very shortly, and CVA expect to deliver the machine in the early autumn. CVA are closely associated with the American firm of Kearney and Trecker and although the detailed design of this new machine has been entirely done in Britain and involves no American patents, it is known as a CVA/Kearney-and-Trecker special machine. CVA have a number of factories in the Brighton area, but their No 6 factory is the newest to be completed and at it they are concentrating on the development of special-purpose machine tools—not all of which are of the transfer type. The firm is energetically experimenting with numerical control, and is co-operating with Ferranti, EMI and other electronic manufacturers.

——CHEMICALS——

Data system handles 2080 points

A data-handling system capable of scanning 2080 points is being installed to supervise operations in a section of the Atomic Energy Authority's gaseous diffusion plant at Capenhurst. Designed, built and delivered by Sunvic Controls in eight months, it is claimed to be the largest in Europe, and will help in the close control which is of great importance in the Capenhurst process. Here gaseous uranium hexafluoride is pumped through porous walls contained in a great number of large cells of approximately 20 ft cube; the lighter 235 isotope (0·7 pc of natural uranium) diffuses faster than the heavier 238, so that a progressive enrichment in 235 is obtained. The operation must be carried out at as low a temperature as possible but not so low as to reach the point (roughly 60°F) at which the hexafluoride changes to the solid state—it has no liquid phase. If this were allowed to happen the pumps and pipes would get clogged up. Mounted on top of the cells the scanning units of the Sunvic logger cover temperatures of gas (upper and lower limits), pump glands (upper limit only), water cooling for the pumps, and the bearings of the 250 h.p. driving motors, as well as motor current and voltage. The complete cycle lasts ten minutes and the accuracy of reading is 10·5 pc. If any reading goes off normal a visual alarm is given and an alarm printer built into the logger unit records time, identification and reading of the point in a code showing whether it is high, low or defective.

Each unit monitors signals from a group of four cells and there are 8 units in all, so that information from 32 cells is passed to the central control room. This is equipped for printing on demand a tabulated log showing the value at all measuring points on any one of the cells together with cell identification and time of scanning; any point exceeding proper limits is shown in red. For use in case of a failure in the automatic scanning full manual control is also provided; and the whole unit is sealed and kept at about 2 in. w.g. to keep dust out. Two mobile print-out units are being supplied. Equipped with electric typewriters they can be plugged into any cell sub-unit so that its operation can be studied in detail on the spot as the complete data—normal or otherwise—are printed out, without interrupting normal scanning of the other three cells in the group.

——ELECTRICITY——

Grid centre uses auto-recorder

Messages and instructions between the Manchester control centre and its ninety grid switching and generating stations are

now recorded by a multichannel installation made by Simon Equipment Ltd; it is capable of eighteen hours' uninterrupted recording on four channels simultaneously and incorporates a unit to supervise time identification in the form of Morse-coded signals at one-minute intervals. The apparatus is brought in to action on traffic demand by a voice operation unit and gets up to full speed in about 100 millisec. It is the only one of its kind put in by the Central Electricity Generating Board so far, but the Board say that they are considering the possibility of using similar equipment on the other grid control centres.

IN BRIEF

Radar speed check A portable electronic traffic analyser—PETA—now in production by Marconi, is designed to discriminate between individual vehicles down to 8 ft apart and will automatically lock on to any car.

Maxam A new company—Maxam Power Ltd—has been formed from The Maxam division of Climax Rock Drill and Engineering, a member of the Holman Group. Main products will continue to be pneumatic cylinders and valves for control equipment.

Dry cells The Ever Ready Company have installed photo-electric controls on their Batrymax dry cell production lines.

France Electronics industry earnings in 1957 were 17·5 pc up on 1956; average increase throughout all industries was 13·5 pc.

Poland The Short Analogue Computer shown at the Poznan Fair is now being studied and used at the Institute of Automation at the Polish Academy of Sciences. The only other computers of this type in Poland are a large analogue—said to be erratic and almost useless for serious research—and a small desk-type Russian computer of 1 pc accuracy.

Russia An open hearth furnace to produce 800 tons of steel per heat is being designed at the Kharkov Steel Plant Designing Institute; it will be automated and based on new methods of fuel burning, slag disposal and rapid charging. Only natural or coking gas is to be used as fuel.

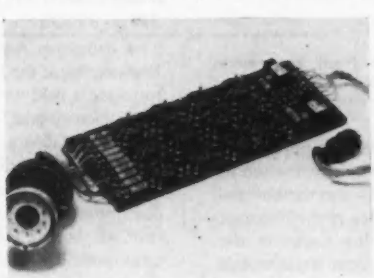
Russia A new remote control system has been tested for the Stavropol gas fields; it is reported to show and record gas output at every well in a 20 mile range, pressure of gas in collectors and the position of gas throttles.

United States Sales of computers are increasing again after last year's slow down. Burroughs Corporation reports a record of about $8·5 millions in May for its larger models. Turnover of computers by Royal Precision and Remington Rand has also increased.

GENEVA: Instrument firms will show their contribution to atomic energy

With the world's first nuclear power station at Calder Hall feeding 80 MW into the national Grid, and four more stations of outputs ranging from 250 to 500 MW actually under construction, Britain is leading the world in nuclear energy development. The astonishing growth of this new industry has been helped by a host of firms, large and small, who have helped to solve the many technical problems involved. Not least of these has been the call for more and better instrumentation and control equipment, and many examples will be on show in Geneva at the world's second international conference on the peaceful uses of atomic energy.

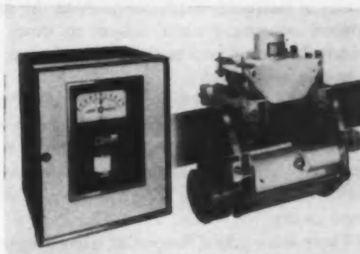
Firms who have trouble with blending processes will be interested in an industrial radioisotope tracer system by Nuclear Enterprises Ltd which will be on show for the first time. To study the flow of a process the paths of injected short-lived radioisotopes are followed by means of a scintillation spectrometer and four detector heads; these may be placed up to 300 ft away from the control point. A further example of nucleonics used for quality and production control will be found on the stand of Ekco Electronics Ltd. One of the Ekco nucleonic gauges has been built into a system to regulate the 'screw-down' at each side of a rolling mill. In this way the measured radiation from a radioactive source can control the thickness of a rolled material. A special nucleonic gauge is to be shown that will measure the thickness of materials to which access can only be made from one side. A pulse height analyser is a valuable instrument for atomic radiation studies and a new one is to be shown by Sunvic Controls Ltd. It is largely transistorized and uses a ferrite core storage matrix, which stores information by magnetizing or demagnetizing a small piece of magnetic material. This principle of information



New Avo sorting unit has a neat magnetic indicator

through magnetization is also used in the Sunvic magnetic memory storage drum, which has a store of about 500 000 binary digits. This drum will be used for a computer in the Berkeley nuclear power station. Also using ferrite magnetic cores is the new Avo magnetic-memory scaling unit. The power required to operate the unit is just over 3 mW for a rate of 1000 counts/second. The magnetic indicator uses the currents in the circuits to magnetize thin strips of metal placed around a balanced pair of compass needles, and the state is shown by a neat dial. Negretti and Zambra are demonstrating a pressure amplifier for remote indication of small pressure fluctuations and a gap-measuring probe which employs a transmitting capsule built up from their diaphragms and is meant for gaps in awkward places.

Parts of reactor control systems which they have supplied to AERE, Harwell, are to be exhibited by H. M. Hobson Ltd. These include coarse and fine gearboxes, and the associated servomechanisms to position the control rods of a reactor. A new item is the honeycomb isotope unit which can hold a large number of isotopes inside a reactor tube. Any desired isotope can be brought out when required without disturbing the others. A winding mechanism for control rods driven by a



This Ekco nucleonic gauge can be strapped to any convenient pipe

member of their new range of stepping motors will be shown by the Sperry Gyroscope Co Ltd, as well as a servo-driven control rod position indicator.

As might be expected, Elliott Bros (London) Ltd and their associated companies are showing a wide range of equipment for the instrumentation and control of a nuclear power plant. One type of Gordon butterfly valve is made to seal tightly by allowing the previously heated valve body to contract upon the valve when it is in the closed position. Working demonstrations of the Elliott reactor simulator are to be given. The Solartron Electronic Group are also to show a reactor simulator. Ferranti Ltd will be displaying the Mercury high-speed electronic computer.

A new instrument shown by the Cambridge Instrument Co Ltd is their centre-line controller. One of the two forms in which it is available is a simple on-off controller. The other form is designed for conditions where on-off control is inadequate, and it is not thought worthwhile to install expensive equipment. The desired and actual values are projected on to a screen and can easily be read.

SELECTED BOOKS

Practice in theory

Theorie der Relaissysteme der Automatischen Regelung *by* **JA S. Zypkin.** *Munich; Oldenbourg. 1958. 472 pp DM 52*

Automatic control by means of relay systems has undergone tremendous development in recent years. This book leads to a clear understanding of such systems and will be found useful to both undergraduates and practising engineers provided that they have a basic knowledge of the elements of linear control system theory.

Design methods unfolded in this book are based on analogous concepts and methods which have proved themselves in the handling of linear system design: Laplace transform methods, and frequency and time-response characteristics; the concept of describing functions and phase-plane methods are developed for the solution of specific problems.

Closing chapters are devoted to problems arising in stabilization, linearization and the optimizing of control systems: and the difficulties arising from natural frequencies are fully dealt with. An appendix contains all the necessary data for design procedures, including Laplace transforms, Fourier series, step functions and tables of functions. Such questions as the design of multi-variable control systems, systems subject to shock impulses or those in which the parameters of the linear portions suffer transient modifications, are excluded.

Much of the book is devoted to practical examples illustrating the basic functions and general properties of non-linear systems, but it must be emphasized that the book is essentially theoretical in concept and in realization: in this connexion Dr Zypkin quotes Boltzmann, who said, 'There is nothing more practical than a good theory'.

There is an added flavour of interest in this book in that it is a translation from a Russian book, first published in 1956. A great deal of original work has been done in Russia on control systems in general, and the bibliography contains many references to it.

Dr Zypkin is a leading member of the *Institut für Automatik und Telemechanic der Akademie der Wissenschaften der USSR.*

The book is well written and the illustrations are first-class. It would have been interesting to have had the author's comments on the probable use of information theory as a future tool for the control system designer: but the book is already a longish one.

L. MACQUISTEN-WALLACE

Single-line working

Procedure for obtaining Transient Response from Frequency Response, with Tables and Nomographs *by* **V. V. Solodovnikov, Yu. I. Topcheev and G. V. Krutikova.** *Infosearch. 1958. 196 pp. £2 2s.*

Floyd's method* for calculating the transient response of a linear system from the frequency response employs an approximation to the Fourier integral relating the two responses. In this method the curve of the real part of the frequency function, plotted against frequency, must be approximated to by straight-line segments; the contribution of every segment to the transient response $f(t)$ is looked up in a set of tables, once for each segment and each value of t; and the contributions are summed to give $f(t)$.

To any designer intending to use this method this monograph can be recommended. Besides the function tables, occupying over half the book, there are what we call Nichols charts and *M*-circle diagrams (the 'nomographs' of the title), together with the relevant theory, so that the reader is given all the equipment and can start from scratch. It is, however, entirely a one-track work and does not mention any other method. The numerous examples, though excellently practical, are all of the type 'Find the transient response of . . . ' and not 'Design a system to satisfy . . . ' It is in no wise a textbook on control theory.

The translation and production are good. The references, nearly all to Russian literature, can mostly be paralleled in English. There is no index.

(The function tabulated is

$$h_\kappa(t) = \frac{2}{\pi}\left[\mathrm{Si}\,(\kappa t) + \frac{1}{1-\kappa}\left\{\mathrm{Si}\,(t) - \mathrm{Si}\,(\kappa t) + \frac{\cos t - \cos \kappa t}{t}\right\}\right]$$

to four decimals for $t = 0$–50 in steps of 0·2 and $\kappa = 0$–1 in steps of 0·01).

N. REAM

* Brown, G. S. and Campbell, D. P.: 'Principles of Servomechanisms' (John Wiley, 1948).

Some chemical engineering processes

Separation and Purification of Materials *by* **Rolt Hammond.** *Heywood. 1958. 337 pp. £2 10s.*

In trying to produce a technological textbook of interest to both the graduate and the non-graduate the author has certainly attempted something very much worth while, and the difficulty of achieving such an object satisfactorily can be judged by the dearth of this type of book. It is therefore not surprising that the result does not quite succeed in reaching this high aim. Probably one of the main difficulties is that the book covers a very large field, which does not make it easy to deal with any one aspect sufficiently to present an adequate amount of data on the equipment available, factors affecting the choice of equipment and means of assessing the performance. To give a typical example of this one can take the chapter on size separation. This deals in some detail with screens manufactured by Russell Construction Ltd, but does not mention the very well-known Locker screen. A very useful inclusion would have been some data on various standard sieves, as misunderstandings on mesh size frequently lead to confusion in practice. Similarly under separation of solids from gases some information on cyclone sizes and pressure drops would have been invaluable but has unfortunately not been included. The author has probably also made his life rather difficult in the way he has subdivided his subject-matter, e.g. air separation appears under separation of solids, whilst sedimentation and fluidization appear under separation of solids from liquids; as far as their separating function is concerned all these depend on fluid drag and terminal falling velocity and they should be classified together. Finally there are important omissions in the book, such as the failure to mention the processes used for separation of gases by liquefaction.

L. MITLIN

Grasp all, lose all?

Automation in Practice *by* **S. E. Rusinoff.** *Technical Press. 1958. 269 pp. £2 15s.*

This expensive American book, by the Professor of Mechanical Engineering at the Illinois Institute of Technology, sets out to cover too wide a field within the given space and fails even to approach a satisfactory goal. It purports to discuss various types of controls and control devices, materials handling and assembly, production of metals and metal working, welding and inspection and quality control. The result is that under each heading there are elementary descriptions of equipment and processes, mainly proprietary, which read as though they have been taken from the manufacturers' catalogues. Little information is given other than brief descriptions of plant. Of the one or two worked examples, how to calculate the force on a piston on page 35 is typical. Many of the half-tones and diagrams also do not give much information and could be omitted. It is difficult to assess to what readership the book could possibly appeal. By its arrangement, however, it does give emphasis to the need for integrating the various production operations in order to achieve automation.

Any reader seeking information on the various subjects covered by this book would be well advised to go to books specializing in the particular subjects.

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INVENTIONS

notes on recent patents in the control field

A more compact diaphragm valve

In Fig. 1a is shown a diaphragm valve whose position is given by the value of the control pressure (1). The pressure sensitive bellows (2) regulates the scale flow through the nozzle (3) from the main supply (4) to the diaphragm valve. The valve will be in the open position when the leak flow is at a maximum through the nozzle, i.e. when the

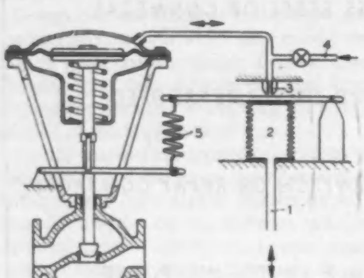

Fig. 1a A typical diaphragm valve whose position is controlled by a flapper-nozzle

control pressure is at its minimum value. If the pressure of the controlled fluid rises the valve will be displaced and this movement is transmitted through a linkage and a spring (5) to change the leak flow through the nozzle. The change in leak flow will be in the direction which will return the valve to its original position. This patent describes a device to replace the spring by a torsional device which is shown in Fig. 1b. The top of the pressure sensitive bellows bears on to an arm (6) which is fastened to a torsion rod (7). The other end of the torsion rod is connected by an arm (8) to the stem of the

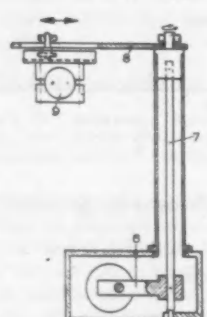

Fig. 1b The torsion rod which it is claimed will lead to more compact design

control valve (9). It is possible to adjust the relation of the arm to the torsion rod, and also of the rod to the valve stem by a stud and slot device. Any movement of the valve stem is thus passed to the bellows through the torsion rod. The patent is not limited to diaphragm valves and it is claimed that the use of a torsion rod instead of a helical spring leads to a more compact design.

794 108. Fluid pressure servomotor-control systems. **Samson Apparatebau-AG.** 30th April 1958.

Magnetic drum in thickness control

The thickness of a textile material or of a coat applied to it is kept at a predetermined value by comparing the signals from two thickness sensing elements, one before the process roller and one after. So that the comparison is done on the same piece of material the signal from the first element is recorded on to a magnetic drum revolving at a speed proportional to the speed of the textile material, and then played back from another head at a time when the material element to which it corresponds is at the second element. The played-back signal is converted from a frequency modulated wave to an amplitude modulated wave, rectified and filtered to a d.c. signal. This direct voltage is compared with that from the second element and the difference used to control the roller.

788 061. Automatic linear dimension control systems. **General Electric Co.** 23rd December, 1957.

Double integrals by analogue

This machine is used for computing the double integral of a function with respect to time. A rectangular moving coil (1) with a substantial moment of inertia is free to rotate between the poles (2) of a cylindrical armature, which is itself mounted on ball bearings (3). The two poles are energized through slip rings from a constant voltage source. The moving coil is fixed to a double armed lever (4) the arms of which project through clearance slots in the armature body. The weights at the ends of the lever are used to adjust the moment of inertia. An arm (5) from the armature body supports a lamp, two photocells and a mirror system coupled to the vertical lever (6) on the moving coil. Together they detect any displacement between the moving coil and the armature and through a follow-up servo driving a gear (7) cause the displacement to be nulled. If an analogue voltage is applied to the moving coil through slip rings (8) the coil is given a torque and hence an angular acceleration proportional to the analogue voltage. The displacement of the moving coil is mulled by the follow up servo driving the armature gear so that the armature rotates. It is shown in the patent that the angular displacement of the armature represents the double integral of the analogue voltage with respect to time. The angular velocity of the armature represents the first integral and is measured by a tachometer driven from another gear (9). The patent

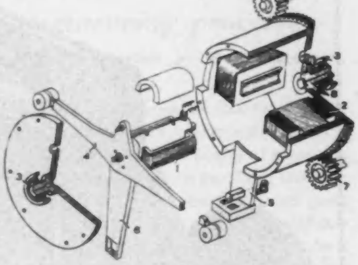

Fig. 2 A device which can compute the double integral of a function with respect to time

goes on to describe an apparatus with two integrators which is used for simulating the behaviour of a ground-to-ground missile guided towards a movable target.

793 374. Machines with movable coil members. **Giravions Dorand.** 16th April 1958.

Speed control by load variation

The speed of an electric motor is controlled by the load applied to an alternator driven from the motor. The load is varied by changes in phase between the alternator output and a reference voltage. The reference voltage is accurately maintained and is applied to the grid of the valve together with a bias voltage. The motor which is adjusted to be unable to sustain its normal

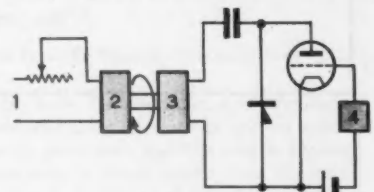

Fig. 3
1 Power supply
2 Motor
3 Alternator
4 Reference voltage

load, so that the maximum load imposed by the valve is speed controlled. Alternatively the reference frequency may be adjustable, and the capacitance should have a value such that in conjunction with the inductance of the alternator it forms a tuned circuit resonating at approximately the alternator frequency.

793 458. Automatic speed control systems. **Muirhead & Co Ltd** 16th April 1958

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications can be obtained from the Patent Office (Sales Branch), 25 Southampton Street, London, WC2. Price 3s 6d a copy (including postage, inland and abroad)

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CONTROL BUYERS' GUIDE

to manufacturers and suppliers

JULY 1958

ADDITIONS AND CORRECTIONS—1

AUGUST 1958

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